



# Towards understanding the design of playful bodily extensions via body schema and body image

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## ABSTRACT

Interaction designers are increasingly interested in physically extending people's bodies and emerging work shows the potential of such bodily extensions for play, one example being interactive fantasy ears for the Cosplay community. We interviewed five designers of four playful bodily extensions to better understand how to design them. Based on their insights and our examination of prior work, we argue that such extensions can be characterized by the extent to which they alter the wearer's body schema and body image. We illustrate this characterization using a two-dimensional design space. We use this design space to articulate practical strategies for the design of future playful bodily extensions. Ultimately, we hope to bring more playful experiences to people's lives.

## 1. Introduction

Interaction designers are increasingly interested in opportunities to physically extend people's bodies. For example, designers have developed systems that give users an additional pair of robotic arms when their existing arms are busy (Sasaki et al., 2017) or an additional hand when their existing hands are already holding other things (Leigh and Maes, 2016). These systems reflect a broader body-centric (Mueller et al., 2018) HCI trend, which often features a tighter integration (and consequent fusion) between a computational machine and the human body (Mueller et al., 2020). The proposed benefits of such integrations are, so far, mostly instrumental, which suggests that the resulting fusion could help people be more productive with their tasks, as with the arm and hand examples noted above. However, systems are emerging that go beyond task support and focus on experiential aspects. One example is the interactive ears system that is worn on the head (Necomimi, 2021). The wearer's ears wiggle based on their emotional state, which is captured via tracking of their brain activity. The target user group is the Cosplay community (with Cosplay – a blend word of “costume play” – referring to a “subculture whose members emulate characters from geek media” using striking costumes and fashion accessories – which are increasingly designed commercially, for example by Cosgear (2021) – in

venues apart from the stage, with popular sources being anime, comic books, and video games (Mason-Bertrand, 2019)). We believe that the consideration of experiential aspects is important for the future of bodily extensions. If we know how to design bodily extensions that people *want* (rather than *have*) to wear, they might enjoy donning them and recommend them to others. Furthermore, long-term continuous use might increase the chance that a fusion between the human body and the bodily extension occurs (Mueller et al., 2020). In these respects, we welcome this growing interest in the experiential aspects of bodily extensions. However, should designers wish to engage with such experiential aspects, they will find available design knowledge limited, and we believe this limitation will hinder the field's growth. To address this limitation, our work aims to expand design knowledge relating to bodily extensions. Given our interest in the experiential aspects, we focus on playful bodily extensions (as per our example above) because they effectively highlight the experiential potential of bodily extensions. Our interest in playfulness is driven by it prioritizing “engagement over external consequence, realness, or convention”, where playfulness is not “a ‘what’ or a ‘why,’ but a ‘how’” (Masek and Stenros, 2021) as highlighted by being a self-motivate activity (Matjeka and Mueller, 2020) manifesting joy, a sense of humor, and physical, social, and cognitive spontaneity (Barnett, 1990). We focus particularly on bodily extensions

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in the form of physical computational artefacts that are attached to the human body and extend the body both physically and experientially for play. We believe that play can aid in bodily extensions becoming more widely adopted. Through play, people can shield themselves from the rules and issues of everyday life (Huizinga, 2016; Stenros, 2014), and play opens up opportunities for exploration and experimentation that are not easily appropriated in everyday life. Furthermore, play allows the exploration of situations that otherwise would be subject to ordinary life discourses (Deterding, 2018). Furthermore, play can establish a protective frame (Apter and Kerr, 1991) that can support a safer environment for exploration, lowering barriers to having bodily extensions accepted in everyday life. We find this latter point particularly important because bodily extensions can usually be easily removed when the wearer no longer wants to play, thereby aligning with play's trait that it should be easily stopped if the player chooses to do so (Matjeka and Mueller, 2020). Overall, we hope that our work can bring value to the overall development of bodily extensions and shed light on how to design for the experiential aspects of extending one's body.

To achieve this, we draw on two conceptualizations of a bodily experience: body schema and body image (De Vignemont, 2010; Gallagher, 1986; Weiss, 2013). We believe that these two concepts are useful for making sense of the user experience resulting from playful bodily extensions. Specifically, these concepts allow us to understand how the user's body is extended physically and experientially (body schema), and how the bodily extension changes how the wearer sees themselves and how they perceive that others see them (body image).

We interviewed five designers of four different playful bodily extensions. Based on their insights and our examination of prior work, we argue that these extensions can be characterized by how they alter the wearer's body schema and body image. We use these two conceptual lenses to examine the bodily lived experience of wearing bodily extensions, generate a design space to identify bodily extension design opportunities and challenges and identify strategies for designers aiming to create future playful bodily extensions.

- We intend for this article to present a useful starting point for future investigations in this emerging area of research. The following stakeholders might find our contributions useful:
- HCI researchers with an interest in understanding, analyzing and evaluating bodily extension experiences,
- researchers with an interest in body-centric approaches in HCI that involve experiential aspects,
- design practitioners seeking practical advice on how to create playful bodily extensions,
- developers of bodily extensions for instrumental purposes who are considering the use of play to lower acceptance barriers for their devices,
- designers who want to go beyond virtual additions to the human body by physically extending the user's body, and
- engineers of existing bodily extensions who wish to know how to modify them to support more experiential aspects.

Sections 2 of this article discuss related work to answer the research question: "How can we describe the experiences of playful bodily extensions to help design them?" We argue in Section 3 for the value of looking at wearers' playful experiences through body schema and body image to develop a two-dimensional design space. Section 4 presents our approach of engaging with designers. In Section 5 we provide a description of four of the designers' bodily extensions. Using interviews and our examination of prior work, in Section 6, we use the two dimensions to articulate four bodily extension user experiences. We then utilize these four user experiences to describe where the bodily extensions from Section 5, as well as prior work's systems, sit within the design space (Section 7). Section 8 presents a set of design strategies for future playful bodily extensions. We conclude the article by discussing the limitations of our work and considerations for future research.

## 2. Related work

Prior work on bodily extensions in HCI (especially their experiential qualities, given our interest in play), guided our work and is discussed in the following sections.

### 2.1. Bodily extensions and HCI

When thinking about bodily extensions, prostheses often come to mind. However, prostheses aim to replace lost limbs and are, therefore, distinct from the bodily extensions we consider in this article. Nevertheless, we note that HCI has investigated prostheses and has identified various ways to control them, including via brain signals (Bright, Nair, Salvekar, and Bhisikar, 2016; Guger, Harkam, Hertnaes, and Pfurtscheller, 1999), motion sensors (Resnik, Klinger, Etter, and Fantini, 2014), muscle sensors (Castellini and Van Der Smagt, 2009; Madusanka, Wijayasingha, Gopura, Amarasinghe, and Mann, 2015) and voice input (Mainardi and Davalli, 2007). We believe that the diverse ways of controlling prostheses can also be used to control bodily extensions, as our designers' systems (Section 5) demonstrate. Prior work highlighted that some users enjoy dressing their prostheses rather than making them blend into the background (i.e., painting them in their skin color), thereby using the prostheses as a vehicle for self-expression (Hutchins, 2017; Vainshtein, 2012). For example, some users adorn their prostheses with jewel stones or decorate them to resemble superhero armor (ABC News, 2015). These prior works highlight that we, as interaction designers, should not underestimate the power of supporting experiential aspects when it comes to bodily extensions.

Prior bodily extension works mostly focused on instrumental aspects. For example, bodily extensions have been proposed as storage areas around the body (Ding et al., 2021), as tools for balance training (Xie et al., 2019), and to help users carry heavy items (Leigh et al., 2017). Furthermore, bodily extensions controlled by another person have been proposed to help the wearer with tasks they cannot solve alone (Saraiji et al., 2018). In contrast, we are interested in the experiential aspects of bodily extensions.

Nevertheless, we are inspired by side notes such as the comment by Leigh et al. who proposed that their bodily extensions could help to play the guitar (Leigh et al., 2017). In response, we are keen to understand what potential bodily extensions offer for play (Matjeka and Mueller, 2020; Mueller et al., 2019; Mueller, Matjeka, et al., 2020). Although bodily extensions might be useful to, for example, play chess (whereby a body-attached robotic arm moves chess pieces around and is a simple game controller), we are interested in the potential of bodily extension for being playful (rather than to control play). This orientation aligns with prior work that suggested seeing the human body as play rather than for play (Mueller et al., 2018).

To guide our investigation, we looked at prior work in art that used bodily extensions as a novel way to see the human body as art rather than using the body for the production of art. For example, artist Stelarc used a robotic third arm as a bodily extension. Interestingly, he did not personally control this third arm during a performance; instead, he invited people to control it over the internet (Stelarc, 1980). This work showed that technology can change how the wearer perceives their body and can affect their self-expression, which speaks to the body image concept we utilize later in this article.

Another example of bodily extensions in art is a set of interactive elephant ears that an actor can wear during a theatre performance (Svanaes and Solheim, 2016). This work showed that bodily extensions can support people to express themselves beyond their own body's capabilities (body image) while highlighting that bodily extensions can extend the human body quite extensively, as is the case with the oversized ears (body schema).

Rapp proposed that wearables can be regarded as bodily extensions and understood from either an externalist or an internalist perspective (2021). Rapp argues that the currently dominant externalist perspective

sees these devices as objects, repositories and instruments with the primary purpose of quantifying, enhancing and enabling bodily actions. We contend that our research answers Rapp's call for more work on the internalist perspective that focuses "on the potentialities of wearables indirectly affecting 'the human' and in integrating with their sensory and intellectual experience" (2021).

While we will propose two dimensions (body schema and body image) to understand the experience of wearing bodily extensions, we acknowledge that prior work suggested three dimensions: the performative, the social and the interactive (Buruk et al., 2019). These three dimensions were suggested to understand how different characteristics of wearable design might affect game mechanics and dynamics primarily at a systems level to encourage a shift towards more imaginary designs, relaxed social interactions, and artifact-oriented interactivity. We also discuss mechanics and dynamics later in the article. Although the performative dimension of this prior work drew on theatrical aspects, which can be associated with body image and body schema, it did not deeply consider lived bodily experiences. More recent works, based on the three dimensions above, generated implications for designing wearables for gaming (Buruk et al., 2021) and playful extended-reality environments (Buruk and Hamari, 2021). These recent works also mentioned around-body interfaces as worthy of further exploration, which suggests that our work could also be useful for the playful wearables field. Nevertheless, these prior works did not specifically examine playful bodily extension experiences, nor did they aim to generate design knowledge for playful bodily extensions, both of which we address in this article.

Just as body schema and body image were both derived from the French "schéma corporel" (Gallagher and Zahavi, 2013; Merleau-Ponty, 1945/1945), we were also inspired by prior work that proposed the use of German terms that refer to the human body to better understand bodily play (Mueller et al., 2018). However, this prior research was concerned with bodily play more generally and only involved screens and no other physical artifacts. Hence, we see our work as being more specific (focusing on bodily extensions). Other prior work on bodily play explored the use of two dimensions to understand experiences: the in-the-moment experience and the reflective experience afterward (Mueller et al., 2020). While we consider the reflective experience when the wearer takes off (offboarding) the bodily extension, we primarily focus mostly on the in-the-moment experience because we believe that it is the in-the-moment experience that is mostly affected when wearing an extension. For example, the reflection on the experience will mostly be "How do I look?", rather than "How did I look?"

Prior work also examined how users can "integrate" with wearables, which highlighted that considering the user experience is paramount as wearers might feel empowered if they think that they control the wearable and believe that the hardware is part of their body (Danry et al., 2022). We built on this prior theoretical work by supplementing it with empirical data from designers' practices while focusing on playful bodily extensions, not just wearables in general, allowing us to present strategies that we believe could guide designers when aiming to create systems that aim to facilitate particular user experiences. As such, our work is forward-looking, aiming to change future designs, complementing the prior work by Danry et al. (Danry et al., 2022) who used theory to be able to "look back" at existing wearable systems.

Lastly, our work extends prior research (Buruk et al., 2023) that analyzed the bodily extensions we present in this article. We extend this prior work by investigating the designs along two dimensions (body schema and body image) and present a new design space generated by the combination of these two dimensions. The combination of these two dimensions allows us, for the first time, to identify four different user experiences associated with bodily extensions. Having access to these four different user experiences allows designers to better understand what they might want to design for their target user group.

In the scope of the knowledge described here, we define bodily extension as computational technologies that are attached to and worn

on the body and physically extend it for experiential purposes, especially playful ones. In this sense, some of the previous work cited here that focused on utilitarian purposes, e.g., training or extending the body for storage, are not in the scope of this examination. Moreover, prosthetics, although functioning as extensions, are not in the scope of this work because of their primarily utilitarian purpose (we acknowledge that they might also be incorporated for playful purposes, however, understanding the playful experiences around prosthetics would require a deeper engagement with and understanding of the experiences associated with limb loss, which is not in the scope of this work). Moreover, we do not include non-technological extensions such as regular costumes, or non-wearable temporary extensions such as a tennis racket. Our examination does also not include wearables that do not (significantly) extend the body, such as a smartwatch.

The prior works suggest that there is potential for bodily extensions to support also experiential aspects. However, there is little work focused on supporting play, and the work that has been undertaken does not contribute substantially to our field's understanding of how to design such bodily extensions for being playful. We point to this knowledge gap as an underexplored opportunity that this article aims to contribute towards filling. To facilitate an expanded understanding of how to design bodily extensions for being playful, we aim to answer the research question: "How can we describe the experiences of playful bodily extensions to help design them?"

### 3. Design space

Prior phenomenological research to understand bodily experiences in HCI guides our work (Mueller et al., 2018, 2020; Svanaes, 2019; Svanaes, 2013; Svanaes and Barkhuus, 2020; Svanaes and Solheim, 2016). In particular, we are inspired by prior work that proposed the concepts of body schema and body image (De Vignemont, 2010; Gallagher, 1986; Gallagher and Zahavi, 2013) and the perspectives by Weiss (2013) and Grosz (2020). We distill these understandings into two concepts with the goal of illuminating a design space for bodily extensions that allow experiencing the body as play (Mueller et al., 2018). Concretely, as we are addressing bodily experiences, we turn to phenomenology. Because we are dealing with bodily extension, i.e., body-worn technologies, these devices affect our actionable possibility space and alter our perception of our own body at the same time. In other words, bodily extensions affect our bodily experience not only through the actions we can do with the device but also by how we perceive ourselves as an extended body among other bodies. To consider and open up this design space and include both sides of bodily experience, we found the two concepts useful. Below, we go through the two concepts and integrate them with our understanding of playful versus gameful as the basis for introducing our framework.

We propose that it is helpful to consider the concepts of body schema and body image to understand the user experiences that playful bodily extensions afford. Both concepts are concerned with how bodily extensions affect how the wearer experiences their own body.

#### 3.1. Prior understandings of body schema and body image

Several theorists have contributed their views on body schema and body image. Vignemont (2011) explained that the body schema is "for action (that is, information about the body necessary for movements, such as posture, limb size, and strength)", while the "body image is for perception (that is, the judgment of one's own bodily properties)". Gallagher argues that "body image is a conscious image or representation, owned, but abstract and disintegrated, and appears to be something in-itself, differentiated from its environment. In contrast, the body schema operates in a non-conscious way, is pre-personal, functions holistically, and is not something in-itself apart from its environment" (Gallagher, 1986). Gallagher offers this definition in response to the fact that the two terms are often confused and consequently used

interchangeably, therefore limiting any “phenomenological studies of body experience” (Gallagher, 1986). Gallagher’s conceptual clarification (Gallagher, 1986), has previously been utilized in HCI (Coyle et al., 2012; Gallagher, 2013).

We acknowledge that our understanding of body schema and body image (and what it means for design) is still emerging (Baumann et al., 2022) and that definitions are still being worked on (De Vignemont, 2010). We note that one of the key writers on the phenomenology of the body, Merleau-Ponty, used the term “schéma corporel” (Merleau-Ponty, 1945/1945) in the original French, which has resulted in two different translations that split the same term into body schema and body image (Gallagher and Zahavi, 2013). This problem of translating bodily terms from one language to another has already been highlighted as a challenge for how interaction design can support the human body (Matjeka and Mueller, 2020; Mueller, Byrne, et al., 2018). To help untangle this problem, we examine body schema and body image as conceptually distinct for the purpose of our investigation. Concretely, we propose to consider the various degrees of body schema and body image alterations along two dimensions (Fig. 3). However, before explaining the two dimensions, and because we examine bodily extensions for play, we discuss the concepts of body schema and body image to include a notion of play by connecting them to the two phenomenological concepts for playful design: gamefulness and playfulness, as described by Matjeka and Mueller (Matjeka and Mueller, 2020).

### 3.1.1. Body schema and body image

In this study, we draw on the phenomenological concepts of body schema and body image. While both concepts originate in the same concept and understanding from Merleau-Ponty’s work on bodily experience (Merleau-Ponty, 1945/1945) emerging from two different translations of this work, theorists have developed these two notions in different directions to emphasize different aspects of bodily experience and what affects it.

Our understanding of the two, as outlined here, is that body schema and body image are not two opposite ideas of bodily experience, nor are they independent of each other. Instead, we believe that the two are interdependent and one affects the other. However, the ways that we can address these two aspects of bodily experience through design are different. And that is where we find these perspectives relevant. Nevertheless, we should be aware that while we address one side of bodily experience in our design, we also affect the other, as none of them exists or can be addressed in solitude. Below, we explain the two concepts, concluding with a section on how they interrelate.

#### ■ Body schema

To Merleau-Ponty, body schema is the body’s pre-reflective organization of limbs and organs. Merleau-Ponty describes how the structure of our body schema provides an actionable structure that allows us to unconsciously perform desired actions. He demonstrates this by explaining how the body schema is disturbed when people lose a limb or have a stroke. The structure of our body schema is created through action and is dynamic, and actions are organized accordingly. That means that it is constantly updated and formed as we act and move. Therefore, when our body schema is disturbed, we cannot perform actions as we used to, as the body no longer knows how to organize itself accordingly. We need to reorganize our schema. This means that we can affect our body schema as a “recorded” structure and organization of our body through actions. While it most of the time happens pre-reflectively sometimes it appears in our consciousness.

#### ■ Body image

While the body schema is dominantly thought of as our pre-reflective bodily experience and bound to our internal organization of bodily actions, theorists have explained body image to be mainly concerned with

our perception and understanding of our body (Gallagher, 1986) (De Vignemont, 2010). As such, we could believe that body schema is for action and body image is for perception. However, as we also perceive the world and understand our body through action, such an explanation might be a bit too divided for our investigation. Instead, we point to how the notion of body image has been developed in feminist theories. We do so because these theories provide a thorough understanding of the interplay between how we perceive and understand our body as we interact in and with the world, which for our investigation, centers around HCI. Concretely, we build on the ideas of the two prominent theorists, Grosz (2020) and Weiss (2013), and their ideas of body image and how they manifest in our encounters with the world.

Grosz examines how we construct body images from societal and cultural expectations. She stresses how the becoming of a person’s bodily understanding comes about in processes of inside out – outside in referring to from where the expectation of a certain body image stems. However, both processes are fueled by the cultural norms that people meet or are confined to and are inscribed in a person’s body image. As such, body image can refer to how a person chooses to appear as well as how the person perceives themselves, i.e., a specific culture or norm. These can be bodily attributes from normative expectations of being strong, tall, thin, or culturally manifested in, e.g., tattoos and clothing.

On the other hand, Weiss has a first-person phenomenological view on body image as intercorporeal. While Grosz stresses the societal and cultural construct, Weiss explains how we create our body image in an intercorporeal process with other bodies. Through empathy and shared bodily experiences, we shape our body image. As such, Weiss stresses interpersonal relations as a factor in the formation of body image, while Grosz emphasizes the social and cultural norms and expectations as a factor.

Both Weiss and Grosz emphasize that body image creation is a continuous and fluid process, similar to how Merleau-Ponty explains our formation of body schema is constantly updated and refined through our actions. In these processes, action is fundamental as norms, expectations, empathy, and interpersonal relations manifest and communicate through action. In this view, body image and body schema become sides of the same coin, where one affects the other. Nevertheless, we can address the sides individually in our designs. And that is where this paper finds its relevance.

Thus, from the above explanations, we draw out the following experiential factors that affect our body schema and body image: social and cultural norms and expectations (Grosz), interpersonal encounters and empathy (Weiss), and the possibility for action and organization of body parts (Merleau-Ponty). Based on these experiential factors, we henceforth refer to our notion of body schema as action space, referring to the body’s possibility space for organizing action, and body image as body inscription, referring to how the technologies are inscribed in our perception of our own body as it is affected by cultural and normative expectations of being a body among other bodies.

Below, we will combine these factors with our understanding of bodily play experiences, and from these understandings, we create a framework for designers to work with in their pursuit of designing playful bodily extensions.

### 3.1.2. Gamefulness and playfulness

In the context of playfulness, we see the body perspectives of body image and body schema together with Matjeka and Mueller’s work around bodily play experiences where they explain the difference between gamefulness and playfulness: being gameful is concerned with bodily achievements and skill acquisition while being playful is concerned with bodily perception stimuli and exploration (Matjeka and Mueller, 2020). The authors explain: being gameful is an “achievement seeking behavior” that refers to the “action of doing something with the purpose of reaching a goal”. Being playful is about “the process of doing something”, rather than the outcome in a “quest for enjoyable bodily perceptual stimuli” (Matjeka and Mueller, 2020).



While the structures of being gameful and playful are not rigid or excluding, they overlap and should be seen as a continuum ranging from the extreme of being gameful; where the wearer's purpose with wearing the bodily extension is only concerned with a bodily achievement or skill mastery, to the extreme of being playful; where the wearer is only concerned with the perceptual stimuli. Similarly, the concepts of body schema and body image also overlap in a similar way; while body schema is concerned with the internal organization of actions and how to perform them, the body image is concerned with perception and cultural or normative appropriation of the extension, and they, too, can be seen on a continuum from how to physiologically structure an action with a bodily extension to the perceptual stimuli of wearing a bodily extension.

In our study of bodily extensions for playfulness, we connect these understandings of body schema and body image with gamefulness and playfulness in the following way:

- Body schema is about how the body organizes its various limbs and organs to perform actions in the world. The body schema provides the structure for such an organisation. We combine this notion with the notion of gamefulness, as they together can shed light on how and why we perform playful actions. Combined, we form this description: Bodily extensions that manipulate or alter the wearer's action space by affecting their body's internal organization in a specific way with the purpose of achieving a specific result or acquiring or improving their bodily skills. Seen from the perspective of body schema, our design space is thus concerned with the specific ways in which a bodily extension alters or manipulates the body's possibility for bodily achievements and skill development and improvement.
- Body image is for our perception of our own body as a body among other bodies, as it is affected by the cultural and normative expectations of our body. Furthermore, there is a social aspect as the wearer's perception of their body image is dependent on the social context in which it is worn. In a playful context, it corresponds to how the wearer perceives to be contesting cultural and normative expectations by wearing the extension and the way it makes the wearer perceive their own body in this context. Thus, seen from the perspective of body image, our design space is concerned with how the wearer perceives that the bodily extension affects how they perceive their body as cultural and normative - or how wearing it contests current assumptions - their own and those perceived from others.

Hence, we contend that prostheses that replace limbs or other extensions with a functional purpose will most likely be primarily altering and affecting a person's body schema because they are mostly concerned with action and skills: what actions can the wearer perform now, which they were not able to do without the extension, i.e., what skills does the prosthesis facilitate for the wearer. Moreover, these bodily extensions can also restore the wearer's body image (their own and socially) to fit current normative and culturally accepted assumptions and expectations. On the other hand, bodily extensions for play will most likely be primarily concerned with body image and perceptual stimuli as they are often appropriated to alter and augment the judgement and perception of the wearer's body. Also, given that bodily play experiences are commonly of an exploratory and experimental nature, Weiss' (2013) explanation helps understand how altering a person's body with a bodily extension can also alter their judgment of their bodily properties not only as a sensory but also intellectual experience. This means that playful bodily extensions could facilitate bodily play experiences that include playing with identities, as we find with the Cosplay community and in carnivals, where people wear different costumes to deliberately alter their own and other's judgments of their bodies. While we know this kind of play as roleplaying or mimicry (Caillois, 1961), the design space we define here is complimentary to roleplay and mimicry as the

bodily manifestation of this kind of play enabled by playful bodily extensions.

### 3.1.3. A high and low degree of alteration to the body schema and body image

To expand upon our proposition that a bodily extension can alter a wearer's body schema and body image to varying degrees, we now explain the extreme ends of the two dimensions. At one end of the body schema dimension are bodily extensions that alter the wearer's body schema "a lot", meaning that the bodily extension significantly alters the wearer's potential for action and bodily achievement, e.g., superpowers. An example of a bodily extension that alters a wearer's body schema a lot is the soft exoskeleton embedded in a tradesperson's clothing that allows them to lift heavier items easily (Auxivo, 2021). At the other end of the dimension sit bodily extensions that only minimally alter the wearer's body schema, neither extending nor reducing the wearer's capacity to act and scope of action (Fig. 1). These are commonly wearables that track body processes for health monitoring, e.g., fitness trackers that track step count and heart rate. These devices are often designed to be as thin and light as possible so they do not unnecessarily disturb movement or direct the wearer's awareness to the device.

At one end of the body image dimension sit bodily extensions that alter the wearer's perception of their own body "a lot", either through identity play or by altering their bodily perceptions internally or externally.<sup>1</sup> For example, a full-body Iron Man costume worn at a carnival could facilitate such a significant change as identity play. At the same time, a suit that changes the wearer's temperature can also change their body image by altering some of their perceptual stimuli. At the other end of the dimension sit bodily extensions that only aim to alter the wearer's body image to a limited extent, or "a little". For example, hearing aids are often designed to be concealed inside the ear and feature a transparent color, with the intention that the wearer is not seen as having a hearing impairment (the effectiveness of this is debatable, but from personal anecdotes, we know that some people wear their hair so as to conceal their hearing aids). As such, we believe we can say that these designs intend to alter the wearer's body image only minimally. These extensions affect the wearer's body schema as they aim at restoring their bodily abilities to "normal". As argued above, prosthetic limbs are also restoring a prior bodily state. Depending on how visible the prosthetic limb is (Saradjian et al., 2008), e.g., if the wearer of a prosthetic leg is wearing shorts, it can contest current norms of how a leg looks and thereby affect the wearer's perception of their own body as a site for cultural and normative bodily understandings. Hence, we place them slightly more to the right on the dimension (Fig. 2).

We derive a design space by combining the body schema and body image dimensions, drawing them perpendicularly (Fig. 3).

While prior work has examined these dimensions in isolation (Baumann et al., 2022) and in combination (De Vignemont, 2010; Gallagher, 1986), they have not yet been connected to design for playful experiences. Furthermore, we argue that considering these dimensions together and connected to playfulness can illuminate the design space of future playful bodily extensions. We argue that considering the two dimensions orthogonally in a design space can be helpful for designers, even though some researchers have questioned if the two dimensions are

<sup>1</sup> We distinguish perception from sensory stimuli in the following way: Perception is the body's pre-reflective selection and interpretation of sensory stimuli (Merleau-Ponty, 1945/1945). When we talk about perception we thus mean the bodily interpreted and processed sensory stimuli. Thus, when we say that the body image is altered by perception, it is an alteration based on the body's pre-reflective processes and not "raw" stimuli. Therefore, we cannot design something to alter our sensory stimuli and assume a specific experience. In the phenomenological tradition, as this paper draws on, an experience is always subjective, and thus must be validated as such. In other words, the wearer defines their experience - not the design.



Fig. 1. The “body schema” dimension.

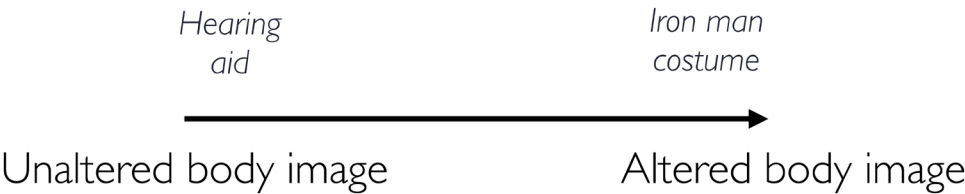


Fig. 2. The “body image” dimension.

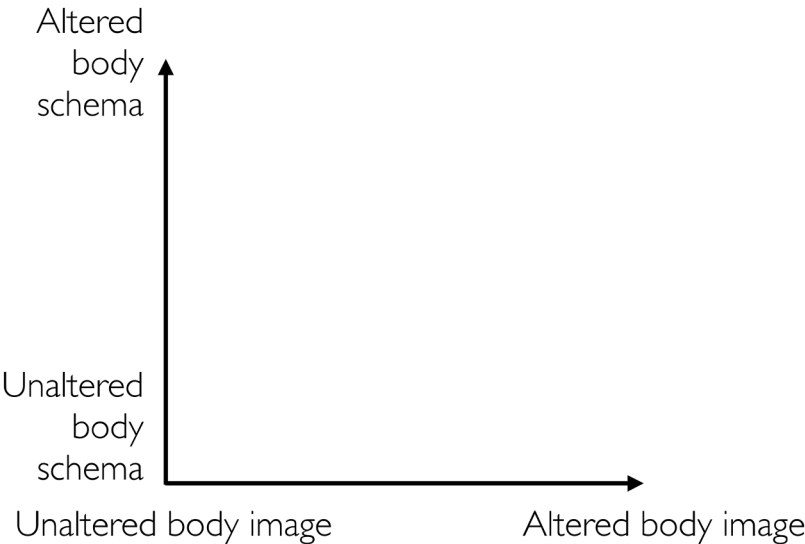


Fig. 3. A design space based on body schema and body image.

completely independent (Grosz, 1994; Pitron et al., 2018; Pitron and de Vignemont, 2017; Weiss, 2013). An argument with which we can agree. Therefore, we stress that we see them in a combined continuum rather

than separate concepts. By connecting them to bodily play experiences, we carve out a significant design space for technologically aided bodily alterations. Our design space intends to prompt designers to consider

both dimensions, particularly how to connect these with bodily playful experiences and how they might facilitate different user experiences. We use the two-dimensional format and visualize them, such as Mueller et al. (2023) did, through a diagram (Fig. 3), hoping that this will be useful for others.

4. Designers

We conducted semi-structured interviews (Longhurst, 2003) with five designers of the following four bodily extensions: Wigglears (Peng, 2021), Arm-A-Dine (Mehta et al., 2018), the Tail (Svanaes, 2019; Svanaes and Solheim, 2016), and Monarch (Hartman et al., 2020, 2015). We selected these four bodily extensions because of their focus on experiential aspects. We note that the designers’ descriptions often stressed their intention to support play and included vignettes of how playful experiences emerged when they wore the bodily extensions themselves. We conducted two one-hour interviews with the designers of Wigglears and the Tail and a two-and-a-half-hour interview session in a focus group setting (Longhurst, 2003) with the designers of Arm-a-Dine and Monarch. While we tried to bring all designers together in one session, the time zone differences made this impractical. All interviews were conducted through videoconferencing. Each session began with a 10-minute presentation introducing all the bodily extension designs to be investigated in this article to all the participants. Our interview questions asked about the design process, possible challenges, prospects, and related playful experiences. We also asked the designers about their recommendations for the design of future playful bodily extensions. We also discussed possible playful applications of extensions that the designers would like to explore.

4.1. Participants

To gain different perspectives on our research question, we selected five participating designers with differing backgrounds and varied experiences of playful bodily extension design (Table 1).

4.2. Analysis

This work has two primary outcomes: the design space and associated design strategies. Both outcomes were created after the interviews were conducted and analyzed. The creation of this knowledge has been a process of designerly engagement with the projects included in this analysis, the interview data collected by expert designers and our previous experiences as designers of similar bodily systems. Therefore, there has been a strong interplay among all those related knowledge, and it is not always possible to pinpoint the types of knowledge, experience, and data that affected the creation of different parts of the design space and design strategies, drawing on the subjective and ambiguous nature of design research as indicated by prior work (Gaver and Bowers, 2012; Gaver, 2012). This section will explain the process that led to the design space and the design strategies created.

The sessions were video recorded, and we transcribed the participants’ spoken statements. We conducted an inductive thematic analysis

of the transcribed data (Braun and Clarke, 2006). First, we uploaded the audio files to a transcription service (Temi, 2021). We checked the transcriptions against the recordings, corrected the text for errors, and transferred the final text files to a qualitative analysis software, Atlas.ti (2021). We undertook open, axial and selective coding of the text files (Williams and Moser, 2019). The open coding resulted in 227 codes. We used the Network Graph function of Atlas.ti for axial coding (Buruk et al., 2023). This coding revealed eight topics: social interaction, body image, body schema, interaction modalities, context, design process, wearability and bodily feelings/experiences. The grouped data was then transferred to a Miro whiteboard (Miro, 2021) for the selective coding and the production of a thematic map. In the Miro board, the codes that occurred across interviews were identified and marked, and the coders recorded their frequency to understand their prevalence. The coder examined each topic, and takeaways were listed. The other authors discussed these takeaways and iteratively developed the final themes.

We did not use the AI features of Atlas TI in this analysis. All the coding was done by Author 2 and associations among codes were also manually defined. The only function we used was the “Network Graphs” that gives a graphical representation of the relationships among codes in the form of hierarchical tree structure which was defined by authors or in places they overlap. This graphical representation helped us to delineate the connections among different themes, and this meaning making was made by the authors through iterative discussions.

Through this thematic analysis process and the numerous discussions, we have developed two types of understanding regarding designing playful bodily extensions. One of them has been a broader understanding of what kind of bodily extensions can be designed when looking through the lenses of body schema and body image. Another was a more detailed and specific understanding of possible practices and strategies of designers to create playful extensions. The creation process of both types of knowledge overlapped and affected each other (e.g., alteration of body image and body schema has been the main driver of the design space. They yielded strategies such as manipulating autonomy by considering altered body schema after onboarding). We formed bridges among those different levels of knowledge by iterating through a back-and-forth between thinking about theory, looking at the data, and our own experiences conducting research in this space. This communication went through meetings, numerous written emails, and iteratively working together on the manuscript online. All authors have been involved hands-on in the final shape of the design space and strategies through discussions and direct editing of the manuscript. We contend (aligning with prior work (Mueller, Byrne, et al., 2018, 2020; Mueller et al., 2014)) that our interest and focus can be advantageous for this work because we can provide first-person accounts from design research practice of both the expert designers we interviewed and ourselves as designers of similar systems. Yet, we acknowledge that this makes replicating our process challenging.

4.2.1. Positionalities of authors

In this section, we will explain the positionalities of each author towards the topic and their backgrounds in designing similar systems to add transparency to the thematic analysis and synthesis process, mainly sourced by the author’s subjective experiences.

Author 1 is an interaction design and human-computer researcher with over 20 years of experience researching bodily experiences. As part of his creative practice, he has co-designed various bodily extensions and worn them. He has also tried several of the works mentioned in this article. He has co-organized workshops and seminars concerned with bodily extensions. He has also co-led several large-scale international HCI initiatives and events. His research goal is to help understand the design of interactive technologies to help people experience their bodies as play, not just for play. This is because he wants to help people figure out who they are, who they want to become, and how to get there. As part of this quest, he has focused on playful bodily extensions, highlighting that they can not only serve instrumental, but also experiential

Table 1  
The designers, their bodily extensions, and their backgrounds.

Designer	Bodily Extension	Background
D1	Wigglears	Software engineering student
D2	Arm-A-Dine	User experience researcher focusing on eating experiences and bodily integrated play
D3	The Tail	Professor of human-computer interaction, focusing on embodied interaction
D4	Monarch	Associate professor and director of a lab focusing on the production of social bodily artifacts
D5	Monarch	Computational fashion and user experience designer

purposes.

Author 2 is a researcher who works on gameful/playful technologies of all kinds with a specific focus on bodily technologies and has experience in designing and developing such technologies for more than 10 years. He is an able-bodied man and is not using bodily extensions in his daily life. He has an interest in practices of producing bodily props for, e. g., cosplay and worked with cosplayers through various projects in the scope of producing playful wearables. He has experience in designing and researching playful bodily artefacts for different contexts such as role-playing and mainstream games, virtual reality and fashion. He is personally interested in bodily extensions and curious about cyborg futures where the definition of the body can be more fluid than today's norms and possible gameful experiences these bodies can afford.

Author 3 is a game designer, entrepreneur and researcher with a keen interest in bodily play experiences and bodily understanding of technologies. She has a prior professional career as an award-winning musician, performing with various international artists. As a game and play scholar, she has designed and produced commercial games through her game studio and produced experimental and speculative games for research only. From these productions, she has extensive experience researching and working creatively toward bodily experiences for serious and leisurely play. Her interest in wearables draws on her background as a musician and includes body-worn musical instruments evaluated both from an HCI perspective and as a performing artist.

Author 4 is a wearables and interactive technology researcher who specializes in creating self-contained systems around the human body. He also has experience in designing and evaluating five bodily extensions with 24 participants across field studies including interviews. His aim is to create body manipulation technology that seamlessly integrates with the schema of the human body while being employed across everyday life activities. Moreover, he eventually aims to contribute to the design knowledge for future systems that are body-conform while offering in-the-moment benefits to wearers.

## 5. Four bodily extensions

We now describe the four bodily extensions created by the interviewed designers.

### 5.1. Wigglears

“Wigglears” that moves the user's ears so that they wiggle in response to the wearer's biodata (Fig. 4) (Peng, 2021). Generally speaking, our ears move in response to changes in our facial expressions, such as laughter, and some people can voluntarily control their auricular muscles to move their ears on command (Bair, 1901). This second type of ear movements, which are often very playful to watch, inspired this work (Fig. 5).

Cosplay community members (hobbyists who dress up as fantasy characters) have discovered the potential of designed ear costumes to express themselves. Commercial products are available that function as bodily extensions, giving people large fantasy ears (Cosgear, 2021). Prior HCI work has also developed interactive elephant ears that can be worn as a costume on stage, as mentioned in Section 2 (Svanaes and Solheim, 2016). There are even brain-computer-controlled ears that wiggle based on brain data, which we tried (Necomimi, 2021).

Wigglears differs from prior approaches to augmenting ears (such as the aforementioned static costume ears (Cosgear, 2021), brain-controlled add-on ears (Necomimi, 2021) and elephant ears for theatre performance (Svanaes and Solheim, 2016)) because the system makes the user's own ears wiggle and does not provide an additional pair of ears. The system achieves this effect through two small servo motors that are attached to a headband, making the wearer's ears wiggle forward and backward based on digital control. The digital control comes from a wearable system worn in a small bag connected to a finger sensor that takes skin conductance data through Galvanic Skin Response



Fig. 4. Wigglears.

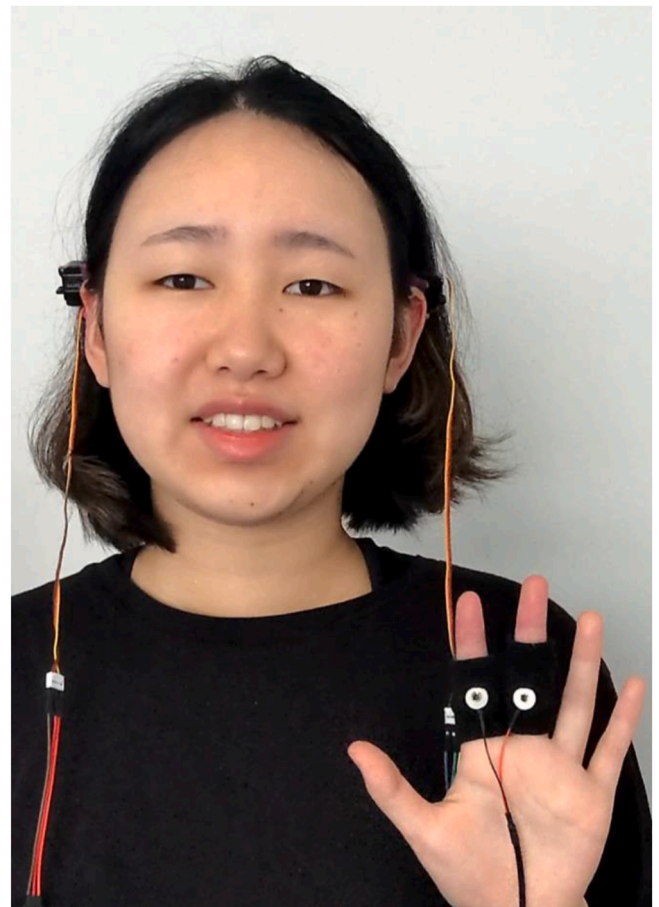


Fig. 5. Wigglears' biosensor.



(GSR) sensing, which is a method of measuring the skin's electrical conductance. More precisely, strong emotions can cause a stimulus to the sympathetic nervous system, resulting in more sweat being secreted by the sweat glands. The system senses these changes (if the user gets excited, surprised, or frightened) and the motors operate and make the ears wiggle.

### 5.2. Arm-A-Dine

Arm-A-Dine (Fig. 6) is a bodily extension in the form of an on-body robotic arm to feed the diner and the co-diner to support the social experience of dining (Mehta et al., 2018). Arm-A-Dine was designed to investigate the practice of sharing food and eating together in a social group and to enhance our understanding of human-food interactions (HFI) (Khot and Mueller, 2019; Mueller et al., 2023). Arm-A-Dine is a two-player interactive system. Each player wears a robotic arm that functions as their third arm. The robotic arm is attached to a vest worn by each player, making it mobile. The use case scenario is a casual eating experience while standing up, as often experienced in conference settings.

Once the robotic arm picks up a particular food item, it feeds it to the wearer or the partner. After picking up the food, the wearer's robotic arm performs actions based on the partner's facial expressions, which are captured by a camera attached to the wearer's vest. The arm will feed its wearer if that wearer's partner makes a "sad" expression. If the partner expresses "happiness", the arm will feed the partner. However, if the system senses neither a particularly positive nor negative expression, the arm will move back and forth in the middle as if to tease both. The system then makes a random choice and feeds either the wearer or the partner.

A study suggested that participants applauded how the system facilitated social interactions between diners and how the system's imperfections contributed to the playful character of the experience (Mehta et al., 2018). Participants mentioned how the third arm made eating and feeding more challenging. However, the experience felt more rewarding once the participant could eat the food or feed it to the co-diner, thus aligning with Suits' notion that playfulness can involve "overcoming unnecessary challenges" (Suits, 2005).

### 5.3. The Tail

The Tail (Fig. 7) was initially developed for theatre play (Svanaes and Solheim, 2016). It later served as a research vehicle (Svanaes, 2019) and is now commercially produced for the Cosplay community to use as part of their costumes (Cosgear, 2021).

The first version of the Tail comprised a mechanical tail for the main character in Ibsen's play, Peer Gynt. The tail was 80 cm long and worn

with a belt around the hip. It was made from piano wires and 3D-printed joints that were controlled by two servos using an external remote control. While the externally controlled tail was subsequently tried on stage in two rehearsals, the actor preferred controlling the Tail himself. Consequently, the second version used an IMU (accelerometer and gyroscope) which recorded the wearer's hip movements and allowed them to control the tail through those hip movements.

The designers wrote about their learnings: "We learned from this [process] that even with scripted movements such as in a play, the user should be in control and there must be a tight coupling between user and the artificial limb" (Svanaes and Solheim, 2016). The Tail was later commercialized for the Cosplay community. It is described to move in the following way: "The Costail moves according to your movements which means that if you move a lot; the tail moves a lot, and if you slow down, the tail will calm down with you. You are in total control, and with practice you can become quite the tail whisperer. As a second option you can loosen the chord [sic] that makes the tail move. This will reduce the movement as well. You can of course change this back later. If you want the tail to move more, you can active [sic] Boost Mode. You do this by leaning forward or backwards for 5 s after turning on the tail. After the tail has calibrated for 5 s, you can try to move your hips in a normal position, and the movement should be bigger and the tail more sensitive" (Cosgear, 2021).

### 5.4. Monarch

The Monarch system (Fig. 8) is a bodily extension attached to the shoulders and activated by muscle movement (Hartman et al., 2020, 2015). The system comprises a kinetic textile that expands and contracts in response to the wearer's muscle movements. The Monarch was designed to explore how bodily extensions can enhance the wearer's body language and self-expression.

Monarch works by responding to the wearer's movements, such as the tensing and relaxing of their arm. The designers believe that "the wearer can express enthusiasm, excitement, assertion, aggression, mischievousness, or even flirtation. In addition, it can be used as non-verbal communication or to accentuate a point in conversation" (Hartman et al., 2020). Monarch looks like regular shoulder pads when the wearer is "relaxed". However, when the wearer is "tense", the shoulder pads expand and reveal a colorful and complex pleated interior. The expanded shoulder pads are aimed to frame the wearer's face, emphasizing their changed mood.

Monarch consists of two servo motors that rotate a wire inside the textile based on electromyography (EMG) that senses muscle movement. The laser-cut acrylic textile used in the first version of Monarch (Hartman et al., 2015) was considered too inflexible. In response, the designers used digital fabric printing on cotton poplin. This change



Fig. 6. Two players eating food using the bodily extension Arm-A-Dine.



Fig. 7. The Tail in different postures. (Brandslet, 2015) Photo: Kai T. Dragland, NTNU.



Fig. 8. Monarch. (Colpitts, n.d.) Photo: Maxwell Lander.

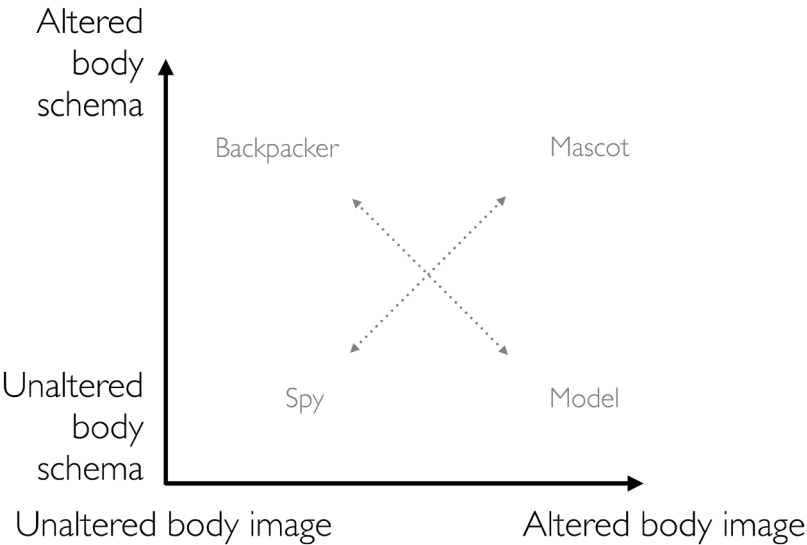


Fig. 9. The four user experiences across the design space.

resulted in reduced production time, more freedom around visual design and color choice, and lighter weight, which eased manipulation by the servo motors. The bodily extension includes a control panel containing an on/off switch, a calibration knob for adjusting sensitivity, and a mode switch that allows the wearer a higher degree of control. The three operating modes are as follows: A, which keeps the current position of the shoulder pads for a prolonged time; B, which adds a threshold to the muscle response, meaning that the wearer needs to tense their muscle above a specific limit to make the shoulder pads expand; and C, which maps the EMG sensor data to the shoulder pads to mimic the wearer's muscle tensioning as closely as possible. While Mode C requires the most attention from the wearer and demands a steep learning curve, it allows for the most fine-grained expression once mastered. The designers concluded that "through continued use, the wearer has the opportunity to augment body language" (Hartman et al., 2015).

## 6. Four user experiences based on the design space

We contend that our design space can help designers by enabling them to identify the quadrant for which they are designing (Fig. 9) and how they interrelate. The main idea behind naming quadrants in a playful and simple way was making them actionable and easy to memorize (following prior work also concerned with bodily experiences that suggested naming such quadrants to make the results more "graspable" for designers, similar to prior work (Mueller, Matjeka, et al., 2020, 2021; Semertzidis et al., 2023)). We see the design space as a continuum rather than four explicit quadrants that do not allow permeability. We now describe each quadrant using our designer's insights and related work, beginning at the upper right and moving anti-clockwise. We discuss how each quadrant connects to playful experiences and the associated mechanics, dynamics and aesthetics we identified based on the MDA framework (Hunicke et al., 2004). The MDA framework has been discussed extensively, and although enhanced versions have been proposed (e.g. (Junior and Silva, 2021; Walk et al., 2017)), we use it here as it appears to be well known within the HCI game design community and might serve to further validate our design space and its connection to playfulness. For each quadrant, we also articulate the opportunities and challenges designers might encounter, and we use our designers' comments to support this articulation.

### 6.1. Upper-right

The upper-right quadrant of the design space is concerned with extensively addressing both body schema and body image by enabling extensive bodily actions and skill focus as well as identity play and contesting normative expectations. Typically, these bodily extensions facilitate unfamiliar bodily playful experiences, where the wearer augments their bodily capacity in a way that disturbs current normative expectations of what we can do and wear in public by wearing and using the extension. Such extensions have a high level of integration between the technical functionality of the extension, i.e., how it affects the body's internal organization with a specific actionable purpose, for instance, gaining a superpower, and how it affects the current cultural and normative understanding of what is possible to do and wear in a public setting. Note here that it is also possible to imagine how wearing the bodily extension in a public setting would feel. Furthermore, this quadrant might occur when a person wears a mascot costume during a sports event. In keeping with this idea, we name the user experiences in this quadrant "mascot" and use it as a metaphor to describe the playful experiences systems in this quadrant might facilitate.

Bodily extensions in the form of exoskeletons are particularly pertinent to this quadrant as they both provide altered bodily abilities and identity play. Moreover, they challenge current assumptions about what to wear and the imagination of bodily technology integration and use cases. For instance, they allow wearers to lift heavier items than they could without the system (Auxivo, 2021; "Exoskeleton report," 2017;

Grand View Research, 2018; Exoskeleton). In addition, these systems can further alter the body schema by limiting the wearer's freedom of movement in some ways while augmenting them in other ways. Also, the characteristically metal-look of these parts can trigger a dystopian futuristic idea of the world that fosters identity play and ludification as it affects a wearer's visual body image. An example might be wearing an exoskeleton in public, which might give the onlookers a reminiscence of robots or cyborgs, which could yield suspicion or fear, and this response might affect the wearer's perception of their body image.

While most exoskeletons appear to have only been investigated for instrumental purposes, "Inferno" (Diitalarti, 2016; Meta.Morf, 2018) is an exception: "Inferno" is an art performance in which the participants wear an upper-body exoskeleton around their torso. The performance setting is a nightclub where the DJ plays music and controls the exoskeletons that participants wear on their arms while on the dance floor, making them "dance". The participants can also voluntarily move their legs according to the music. The experiential character of this performance is a combination of altering the body schema and body image, which places it in the upper-right quadrant of the design space. Concretely it alters the body schema by altering the wearer's bodily abilities in unusual ways. It uses the mechanics of restraints (Matjeka et al., 2021), i.e., playful restrictions on movement, together with distributed powers between the choreographer and the wearer. It alters the wearer's body image as the distributed powers between the choreographer and participant yield augmented perceptual stimuli as the choreographer stimulates and "touches" the participant through the mediated movements through the exoskeletons. Moreover, the participant is wearing an exoskeleton in a dystopian techno-future setting, facilitating identity play of being a cyborg in a dystopian future partially controlled by external forces.

#### 6.1.1. Mechanics

As bodily extensions in the upper-right quadrant aim to alter the body schema and body image quite extensively, any underlying mechanics for playfulness are often aimed at exaggerating existing movements, making them incomplete or awkward (Matjeka et al., 2021), such as controlling the upper body movements through an exoskeleton in "Inferno", contrasting conventional "smooth" dance moves, mechanics that Matjeka et al. coined restraints as mechanics restricting bodily movement or altering their preconditions for bodily achievements (Matjeka et al., 2021). While restraints are commonly used in traditional games and sports, this kind of bodily play experience can be characterized by exaggerated, incomplete or awkward movements that are different from the wearer's current movement repertoire and hence disturb and call for a correction of the body's internal organization of limbs to move according to the newly acquired organizational schema (Merleau-Ponty, 1945/1945). The exoskeleton and the newly acquired movements also contest current cultural assumptions of what to wear and normative expectations of movement behavior, and, therefore, exhibit a great potential for altering the wearer's body image extensively. Therefore, the term "mascot" fits this quadrant, as mascots often use exaggerated and awkward movements to entertain an audience.

This mechanic was also prominent in the robotic arm of Arm-A-Dine, which moved forward and back between diners in a mechanical, rugged way quite different from the usual feeding actions known from human arms. Our designer reported that these awkward movements seemed to facilitate laughter (Scott et al., 2014). However, the design of the associated dynamics and aesthetics is important, which we discuss next.

#### 6.1.2. Dynamics

Dynamics describes the run-time behavior of the mechanics acting on player inputs (Hunicke et al., 2004). With bodily extensions in the upper-right quadrant, this run-time behavior is often aimed at manifesting joy, such as mapping emotions, like joy, to movement. For example, with Arm-A-Dine, people's facial expressions were mapped to arm movement, allowing them to manifest joy when eating something



pleasurable.

Another dynamic is bodily curiosity. The Arm-A-Dine inferred curiosity as the players never fully knew how it would respond (Matjeka and Mueller, 2020). Curiosity, in this sense, is motivating for further exploration and bodily achievement, which affects the continuation of playing. The players will seek to master the arm and continue until they achieve this goal – and have corrected their internal organization of the body schema. Bodily curiosity was also prevalent in the Inferno example, as the participants reported their motivation to participate was about how it would feel to wear and be controlled by an exoskeleton. They reported it as a social experience with their peers in an accepted context, hence the cultural and normative awareness of the alteration of their body schema. In our terminology, curiosity as a dynamic for wearing the bodily extension was driven by a desire to experience altering the body schema and image combined.

### 6.1.3. Aesthetics

As body image concerns cultural and normative expectations, the device's aesthetics, i.e., its appearance, can play an important role in such regard for the wearer. For instance, wearing an exoskeleton like in the Inferno example can have specific cultural connotations of a dystopian future, robotic dominance, human incompleteness, etc. A speculative example of an exoskeleton incorporated in a costume, e.g., a cosplay costume, might have other normative connotations, such as appearing as a teddy bear, displaying a love for animals or other less dystopian or socially horrifying ideas.

Furthermore, aesthetics describes the desirable emotional responses evoked in the player (Hunicke et al., 2004). With Arm-A-Dine, the indented emotional response was laughter. Bodily extensions in this quadrant often focus on “slapstick” – comedy based on deliberately clumsy actions and humorously embarrassing events – to manifest joy, speaking to the “slapstick” of mascots in sports stadiums.

### 6.1.4. Design opportunity

The opportunity for designers to create playful bodily extensions in this quadrant lies in combining features targeting both the body schema and image. As such, to facilitate the alteration of body image, the design focus is to help people experience themselves in roles or identities that are different to those they experience in everyday life, for instance, participating in a dystopian futuristic setting by wearing and being controlled by an exoskeleton as in Inferno. Design opportunities to address the body schema include altering the wearer's bodily formation, as we saw with adding a third arm in Arm-A-Dine or wearing an exoskeleton connected to another body. As this quadrant combines these two approaches, bodily extensions in this quadrant allow the wearers to try out what it would feel like to have a different body by adding alterations to their existing body and experiencing how one would be perceived by others as a response to that change. For example, the “4-legged stilt costume” (GeneralTampou, 2010) is a playful bodily extension that allows its wearer to experience what it would be like to inhabit the four-legged body of a fantasy creature and how others would see it. The designer of the Tail explained this social implication by saying that someone must have a certain “crazy” identity that enables them to wear these kinds of extensions: *“The only reason I could walk around on campus with a tail is because I am [known as] this crazy tail professor.”* As bodily extensions have the potential to extend the body's physical formation quite significantly with consequences for the body's internal organization, i.e., body schema, the extension can facilitate exaggerated movements, as the designers of Monarch indicated, pointing out an alteration in their body schema: *“You actually become more aware of what your body's doing, uhm, because it's kind of extending this small movement [...] those things actually made me more aware of my body”.*

### 6.1.5. Design challenge

The challenge in this quadrant is that wearers may first need to become accustomed to their extensively altered body schema and body

image. Designers should be aware that this transition could take some time. For example, a person wearing the “4-legged stilt costume” (GeneralTampou, 2010) has their arms attached to leg contraptions. They must first learn how to walk with four legs, navigating uneven footpaths, etc. However, acquiring new bodily skills also includes risks of injury. Taking such risks into account, it would be advisable for wearers to learn how to confidently move with the bodily extensions before they venture out into the public domain. How to facilitate this learning process through the design remains an open challenge, but working with dynamics such as curiosity, which is also a known motivator for learning, could aid in motivating to acquire the necessary skills. The designer of Arm-a-dine described this challenge: *“Consider how easy or difficult it is for a new person to get accustomed to that experience. Let's say if it's very difficult and probably people would end up giving it up and like not trying it out, if it's very easy, then again, uh, they would use it and then not, you know, um, continue using it.”* The designers of Monarch explained how they encountered a challenge in how the wearer would organize their body's schema in the situation where their shoulder pads “stuck out” from the body, exaggerating smaller movements of the shoulder that *“made the body take up more space sometimes when you weren't necessarily wanting to.”*

## 6.2. Upper-left

The upper-left quadrant contains bodily extensions that aim to alter the body schema but do not the body image. In bodily play terminology, the wearer experiences altered bodily abilities by giving them superpowers, distributed powers or take-away powers by restricting abilities (Matjeka et al., 2021). We name the associated user experiences in this quadrant “backpacker” because the effects of these bodily extensions remind us of backpackers moving about, wearing large backpacks, and unintentionally bumping into strangers on public transport and knocking goods off shop shelves. However, the backpack also provides the wearer with resources contained in the backpack. While the backpacker's body schema is significantly altered by their large backpack, they often think they just “blend in” as a tourist and are seen as no different from the locals. Hence, a backpack, for us, is an example of an item that might change the body schema significantly while possessing the possibility of not affecting the body image much (at least in a backpacker's opinion).

In this quadrant reside technologies such as shoe implants that make the wearer run faster and electronic rollerskates. The same goes for the hand controllers accompanying a VR headset. It provides the player with superpowers such as with virtual lightsabers. However, they do not alter the player's body image much. Furthermore, they are easily disposed of as bodily extensions compared to, e.g., an exoskeleton or a Mascot costume.

### 6.2.1. Mechanics

The mechanics in the upper-left quadrant are concerned with altering the body's organization to play with bodily abilities while not wanting to contest any cultural norms; hence, they often engage in and experiment with new actions that can be fun to discover. As the mechanics for this quadrant share commonalities with the upper-right quadrant, they also share some mechanics. For instance, the restraint mechanics explained earlier (Matjeka et al., 2021) are also prevalent in this quadrant as they address how to alter bodily abilities and infer restrictions for bodily play experiences. As restraints also include manipulations of the wearer's bodily preconditions, shoes with implants provide a good example of how to affect the body schema but not the body image, i.e., the wearer's actions space but not their normative appearance. Likewise, a pair of game controllers are standard equipment when playing games and, thus, do not contest current normative or cultural expectations. They provide the wearer with an altered action space and using them requires reorganizing their body schema.



### 6.2.2. Dynamics

The dynamics in the upper-left quadrant are concerned with altering the wearer's action space to get superpowers or lose some powers. For instance, shoes that enable super running powers that let the wearer explore and improve their running abilities. This appears to resonate with the notion of "discovery" that has previously been described as a playful element in (game) design, describing the experience of "finding something new or unknown" (Lucero and Arrasvuori, 2010). The notion of "discovery" speaks to the "backpacker" term, as backpackers are known for their desire to discover new places through their traveling. With playful bodily extensions, discovery seems to be facilitated through the on-body mounting, as it allows to, through turning or twisting the body, make the hardware noticeable to others (and oneself).

### 6.2.3. Aesthetics

While designs in this quadrant focus on bodily abilities and mainly address the wearer's internal organization of their limbs to explore and improve actions, aesthetics would be concerned with meeting normative assumptions. Furthermore, aesthetics should focus on eliciting the wearer's understanding and user experience of using the device. The shoe example emphasizes this understanding that a pair of regular-looking shoes can give the wearer the feeling of having superpowers. Similar aesthetics work for the game controllers. The focus is on functionality and user experience. Any cultural or normative divergence focus would be within the body image quadrants.

### 6.2.4. Design opportunity

We believe an opportunity for bodily extensions in this quadrant is to help wearers with their actions or augment bodily perceptual stimulation in various ways while not contesting any apparent culturally or normatively divergent behavior. However, it is important to consider how they feel about receiving this help. For example, as an associated video suggests, while a wearer of the "extendable arm" (Ding et al., 2021) might be supported, they might feel quite awkward about receiving this support. Playful environments might help further. For example, although an alien limb worn on the body might be awkward in everyday life, others would judge it less harshly when worn in a LARP (live-action role-playing) context. The Monarch designers put it in the following way: *"When we're thinking about other playful objects, especially ones that are, like, associated with games or a very specific context, it's very easy to use them in that context, versus something is on your body, hypothetically for an extended period of time."*

### 6.2.5. Design challenge

Design challenges in this quadrant include being aware of how the extension affects the wearer. While it might be interesting to "discover" new action possibilities, it can also be frightening or compulsive to the wearer. In this quadrant, a challenge for the design of bodily extensions is that the wearer might not perceive an altered body image. In contrast, others who observe the wearer's altered potential for action due to the altered body schema might think otherwise. The backpacker scenario above is a case in point. Although the backpacker might think they are blending in, experiencing no altered body image, nearby observers might quickly identify that this person is not local and treat them accordingly. Even with an item such as a backpack, certain situations might trigger the alteration of body image more than expected. Similarly, sudden changes of context might also lead wearers to perceive their body image differently. One example involves Cosplayers at a Cosplay convention stepping outside the magic circle (Salen and Zimmerman, 2003) when they go to the nearby shops to buy lunch. The designers of Monarch gave a similar example of their stepping outside of a conference exhibition space: *"And it just feeling super weird, like suddenly the playfulness faded away and it was just strange"*.

### 6.3. Lower-left

The lower-left quadrant contains bodily extensions with a low degree of altered body schema and body image. Key concepts for designs in this quadrant indicate possible actions while not necessarily carrying them out while simultaneously challenging current assumptions, e.g., right or wrong or do's and don'ts. As such, design indicates certain behaviors and actions. Ludification prevails here as it is about indicating rather than performing the experience (Raessens, 2014).

We call the resulting user experience "spy" because the system supports the wearer's play but does not significantly alter their body image or body schema, i.e., it does not provide any new abilities, unusual perceptual stimuli or costumes, thereby allowing them to play covertly. We use the term "spy" for experiences in this quadrant because they remind us of the spies in Hollywood movies who do not want to appear as anything else but "normal" through clever disguises.

Audio games played with earbuds represent examples of extensions that feature a low degree of altered body schema and body image because they do not much affect the wearer's ability for action. Earbuds are now socially ubiquitous, so we argue that they most likely do not significantly alter their wearer's body image. Indeed, bystanders would not know whether the wearer is listening to music, a presentation for work or school, or playing an audio game, so there is a low potential that they will be perceived to be playing a game (which could be considered "childish" behavior in the workplace).

#### 6.3.1. Mechanics

The mechanics in the lower-left quadrant are often concerned with unusual actions. For example, the ears moving in Wigglears can be considered unusual. Ears do not usually move back and forth like they do with the same compared to ear movement as a result of facial expressions. Our designer said that these unusual movements of the ears often resulted in laughter by bystanders. Unlike the Cosplay ears mentioned above, which are rather large ear extensions, the Wigglears system wiggles the user's own ears, hence the effect is rather subtle, allowing the user to play with how much they reveal their emotions, speaking to the covert behavior associated with spies (explained below). Illusionists work in this space as well. While their tricks are covert, however, very effective, they keep within the magic circle where rules are different from the "norm" (Salen and Zimmerman, 2003).

#### 6.3.2. Dynamics

The dominating dynamic in these experiences is suspense. The dynamics are often concerned with supporting the user in acting covertly regarding the data the bodily extension engages with. In particular, the system often supports the user in using their body to play with hiding or (partially) revealing the extension and hence the associated data, giving them agency (Mueller et al., 2017), speaking to the term "spy" that is often associated with hiding and revealing information to some, but not others. As such, the dynamics can be considered to allow for social spontaneity, a key facilitator for playfulness (Barnett, 1990). Wigglears might serve as an example here: the user can turn their head to hide or reveal their ears to others, therefore hiding or revealing insights into their current emotional state (as the ear wiggling represents current GSR levels). Furthermore, the designer told us that they experimented with different head scarfs, hats, and headbands, allowing them to play with how much of their ear (and hence their ear movement) they can hide and reveal, for example, if long hair is moved forward, they could almost completely hide any ear movement, allowing to (temporarily) not reveal any of their GSR data when trying to stay more private in certain settings.

#### 6.3.3. Aesthetics

The emotional responses that bodily extensions in the lower-left quadrant aim for are often associated with a "spy" experience that plays with tension, such as between service and sacrifice or self and

mission. This reminds us of the notion of “submission” that has previously been described as “being part of a larger structure” in HCI game design research (Lucero and Arrasvuori, 2010) and the notion that traditional spy board games are believed to help children recognize and discuss the feelings of others (Twinkle, 2024).

#### 6.3.4. Design opportunity

In this quadrant, there is a design opportunity to facilitate play experiences without fearing public ridicule for being too playful or childish. Designers can create play experiences that push the envelope of what people might engage in when using traditional interfaces, allowing wearers to “let go” and fully embrace the playful opportunity without worrying about being judged by others. The designer of Wigglears mentioned a similar effect. Compared with other systems analyzed herein, Wigglears is quite subtle how it moves the body, and the system is almost invisible to observers. Due to the system’s subtlety, the user could wear the ears while listening to a lecture and experience what it would feel like to have a device wiggle their ears in a serious context: *“So I wore them once for a lecture. Well, when I was attending a lecture and I realized that it was kind of distracting for the class, ‘cause I was trying to pay attention to what the lecturer was saying, but then sometimes my ears were wiggling and I’ll think to myself: ‘Oh, that’s weird.’”* The user would then reveal it when they wanted to, in an attempt to keep the feeling of suspense.

#### 6.3.5. Design challenge

The aforementioned design opportunity also has a dark side. If bystanders are aware of the play occurring, they might, at best, feel alienated and, at worst, be harmed by an over-enthusiastic player who is heavily engrossed in a flow experience (Csikszentmihalyi, 1990) with their bodily extension and oblivious to the people around them. A similar situation was experienced by onlookers when the designers of Monarch wore the system at a BBQ event: *“I felt like the people who weren’t wearing them felt weird because we had this extra mode of expression that they couldn’t access, you know, so like they couldn’t respond [...]. So, it created this weird hierarchy of nonverbal communication.”* Lastly, a downside to designing for suspense and shock can be that it is not fun and breaks the magic circle described above.

### 6.4. Lower-right

The lower-right quadrant contains bodily extensions characterized by a low degree of alteration to the body schema but a high degree of alteration to the body image as identity play or perceptual stimuli. We name the user experience associated with these extensions “model” because the wearer can perform like a fashion model when wearing them. The dominating bodily play form can be identity play and bodily perceptual stimuli.

When thinking of a traditional example that features a low degree of alteration to the body schema with a high degree of alteration to the body image, the use of makeup comes to mind, especially in the context of art performances such as those at the theatre or in carnival street parades with pantomime performers. Wearers aim to change how they feel about their bodies and how others see them, while the (thin) bodily extension barely alters the body schema. Recent interaction design research has built on this idea, proposing interactive nail extensions (Kao et al., 2015) as well as tattoo-like thin films (inspired by traditional body art) that decorate the wearer’s skin (for example, making it look gold (Kao et al., 2016)).

An example of a “thicker” extension is the “Caress of the Gaze” (Farahi, 2016) dress, which extends the human body with 3D-printed elements (spikes) manipulated in response to onlookers’ gazes. While this dress does not significantly change the body schema (the 3D-printed parts are relatively small), the movement of the spikes can significantly affect the body image as they stimulate the wearer’s visual perception in unusual ways besides interacting with the gaze of onlookers. Another

example of a “thicker” extension that alters the body image by augmenting bodily perceptions and facilitating social encounters is the “Mediating Bodies” project by Hoby and Löwgren (Hoby and Löwgren, 2011). In “Mediating bodies”, a performer is wearing a suit connected to two sets of headphones that make a sound when the performer and a stranger touch each other’s bare skin. This suit does not alter the performer’s body schema, i.e., actions or bodily abilities. But it alters both parties’ perception of their bodies and interconnectedness, as it stimulates their hearing when they touch and thereby alters their body image through augmenting their bodily perceptual stimuli, i.e., combining the auditive and tactile senses.

#### 6.4.1. Mechanics

The mechanics in the lower-right quadrant are often concerned with fluid, smooth, or extended actions, supporting dressing up for identity play, to stimulate bodily perceptions in unusual ways, speaking to the stylish actions associated with fashion models. The bodily extension itself can feature smooth actions, like the Monarch, which features smooth movement of the wings thanks to the in-built wire. The position of the wings allows the wearer to showcase movement to others, as the wings are located quite visibly on their shoulders.

#### 6.4.2. Dynamics

The dynamics mostly concern supporting the user in expressing themselves through the bodily extension. We like the term “swagger” as it highlights a confident and sometimes slightly arrogant way of showcasing one’s body to others, speaking to the “model” term of the quadrant. For example, the different settings of Monarch allow the wearer to finely control how their shoulder pads look, which they can complement with an upright stance that pushes their shoulders backwards, further showcasing their body with bodily extensions. The designers mentioned how they spent significant time on the material and the look and feel of the wings to style their appearance so that it can look fashionable, further speaking to the “model” notion. As such, how the user is perceived is affected by how “proud” they wear them: if walking in an upright gait, with shoulders back, the bodily extensions extend this pose, promoting an imposing figure. If the wearer is unhappy, their shoulders might lean forward and their back bent, with the bodily extensions emphasizing this unhappy feeling. This way, the system exhibits the wearer’s bodily perceptual states. As such, the dynamics in this quadrant are concerned with giving the wearer control over how they want to be perceived by others (and possibly by themselves).

#### 6.4.3. Aesthetics

The emotional responses that bodily extensions in the lower-right quadrant aim for are often associated with playful self-expression where the wearer can use their body (combined with the bodily extension) to choose how they want to be seen by others. This can involve them acting “dressing up”, i.e. being playful in their bodily actions to be seen by others, just like posing on a catwalk. Here, the putting on and taking off of the bodily extension can form distinct start and end points of the experience (McCarthy and Wright, 2004) that demark the beginning and conclusion of the runway walk. This speaks to the notion of “self-expression”, described as “manifesting oneself creatively” (Lucero and Arrasvuori, 2010) in prior game design research, which can be a key driver for playfulness with bodily extensions, we believe.

Moreover, there is an aesthetic experience in the augmented sensory perceptions that designs in this quadrant entail. For instance, the touch suit yields an emotional response of togetherness and caress, which are also prominent in the examples with the Caress of a Gaze example.

#### 6.4.4. Design opportunity

One design opportunity associated with this quadrant is to enable wearers to play with different personas in rapid succession. Given that there is a shallow learning curve when the body schema is barely altered. At the same time, the body image is significantly altered. Users

can quickly try out many bodily extensions, changing from one alternative body image to another to see which one “feels” right, similar to how a model can quickly change outfits and adjust their presence and how they present themselves.

While adjusting bodily extensions might be a part of the fun, they might also repel users if the learning curve for their use is not carefully designed. In this regard, the designer of Arm-A-Dine commented: *“Let’s say, if it’s very difficult and probably people would end up giving it up and like not trying it out, if it’s very easy, then again, they would use it and then not, continue using it.”*

Moreover, perceptual stimuli from, e.g., EMS or touch-enabled devices do not (necessarily) alter the wearer’s bodily abilities, i.e., their body schema: instead, they draw the wearer’s attention to how they perceive their body (image) or parts of it.

#### 6.4.5. Design challenge

As suggested in prior work, an altered identity arising from technology engagement can have implications for a sense of self (Mueller et al., 2020). In this respect, a design challenge is that wearers could use the ability to quickly switch between different bodily extensions in this quadrant so rapidly that they become confused about their own identity. For example, the designers of Monarch mentioned their effort to introduce different colors to wings: *“It used the pink and the kind of light colors. Um, the second one we tried to have different, like, it could be black or brown, like you could dye the leather different colors.”* Although their decision appeared to be more about making Monarch fit personal styles, in a context where those different colors correspond to different messages (e.g., red means “don’t come closer to me”), this kind of quick changes in the appearance and, consequently, in body image might be confusing.

#### 6.5. Playfulness in the design space

We now use the key terms identified in the previous section around how playfulness could be facilitated across the four quadrants and plot

them in our design space. We structure them using the mechanics, dynamics and aesthetics described above. This visualization aims to help designers who want to create a bodily extension in a particular quadrant and wonder how to make it (more) playful or might guide designers tasked with making an existing bodily extension, having located its position in the design space, more playful. This plotting should only be seen as an initial starting point, not a complete picture. Other ways to create playful bodily extensions are undoubtedly possible. However, if it is unclear where to start, Fig. 10 might be a helpful starting point for such an investigation.

### 7. Applying the design space

We now apply the design space to the designers’ bodily extensions described in Section 4 (Fig. 11), complementing the mechanics, dynamics and aesthetics as well as the design opportunities and challenges from the previous section. We use the design space’s two dimensions to describe the bodily extensions (where the dimensions provide a vocabulary to talk about them) and position them concerning one another within the design space, helping to identify similarities and differences. We also stress the importance of seeing the two dimensions as being on a continuum, meaning that there is no distinct line between the quadrants as these are combinations of the continuums. As such, the quadrants exemplify user experiences, where each experience lies somewhere on both continuums, placing it in one quadrant more. This also means that designers can push and pull their designs along the continuums by adding features that either alter or unalter the player’s body schema or image in the explained ways. We demonstrate further how in the following sections. Furthermore, we use the four user experience quadrants to generate design expansions to the existing bodily extensions. We do this to add weight to our claim that our design space has both descriptive and prescriptive power.

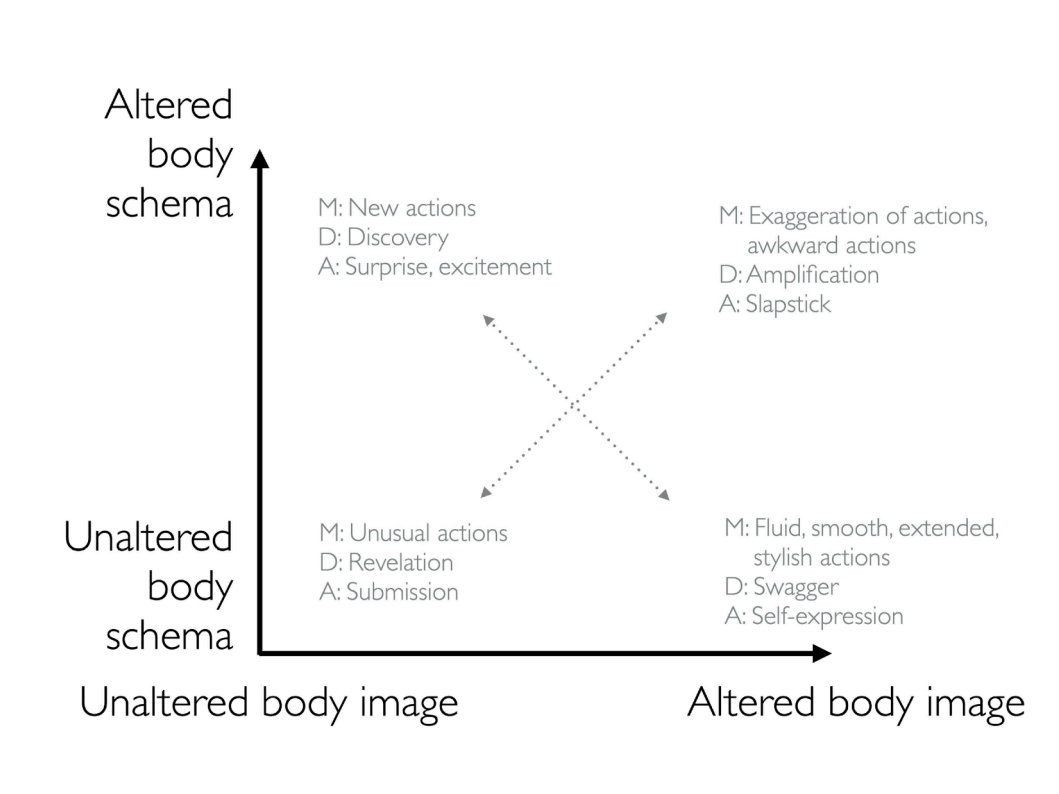


Fig. 10. Key terms identified to facilitate playfulness with bodily extensions.

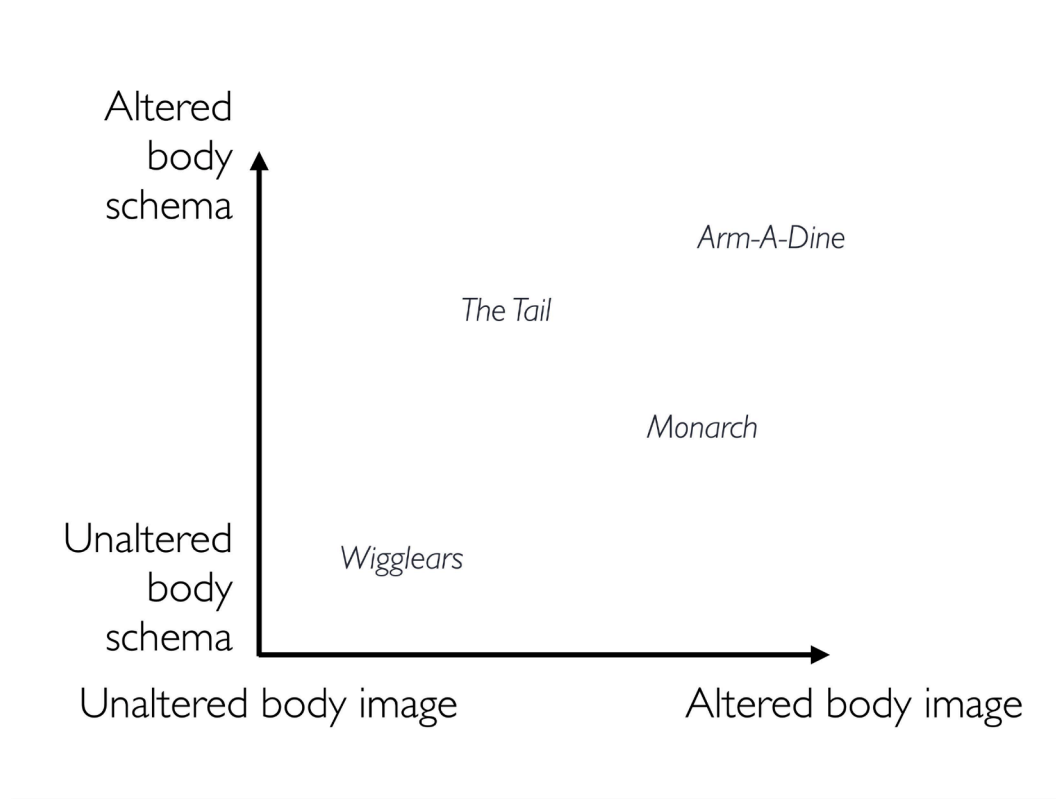


Fig. 11. Applying the design space.

## 7.1. Wigglears

### 7.1.1. Explaining Wigglears through the design space

Wigglears does not significantly alter the body image because the wearer's real ears are wiggling. If the wearer commonly wears headbands, we contend that using the Wigglears headband is also not much of a change, further cementing our claim that body image is not much altered.

We believe that the extent of altering body schema is more complex. On the one hand, if the ears are not wiggling, the body schema is unaltered. On the other hand, if the ears are wiggling, the wearer's body schema is altered, albeit not to a large extent: their ears will be in a different position, and they will only be able to sense this change through proprioception (or by looking in a mirror). However, as the orientation of the ears is not used to affect the action potential, the wearer's body schema is barely altered.

Based on this evaluation, we position Wigglears in the lower-left quadrant. In their interview, the designer corroborated this decision, saying that the system was unobtrusive and only came to the fore in particular situations. They also pointed out situations in which the wearer was unsure that others would perceive the wiggling, such as videoconferences that often have low-resolution images.

### 7.1.2. Extending Wigglears through the design space

The design space helps us to move Wigglears into other quadrants and generate design expansions and alternatives. For example, we could increase body image alteration. This increase could take the form of some of the larger Cosplay ears put on top of the wearer's real ears. If the ears wiggled, they would also wiggle the costume ears, making the wiggling far more visible. We could also add LEDs that light up and change colors while the ears wiggle, highlighting the wiggling. Indeed, the Wigglears designer recounted scenarios in which the wiggling was not immediately visible to bystanders because of its subtle movement. Changes to the size of the ears could also affect the extent of the

alteration of the body schema. For example, very large ears might require their wearers to get used to their body being "taller" when going through small doorframes. Furthermore, the orientation of the ears could affect the wearer's ability to locate the directional source of a sound and hinder or improve hearing. Such changes could alter the wearer's ability for bodily action while augmenting their bodily perception, thereby adding features to position it farther up-right in the design space. For example, if the ears are oriented in a direction that allows only the Wigglears wearer to hear a cry for help from afar, they could facilitate the wearer springing into action to help while others, who are unable to hear the cry for help without the ears, could not. Moreover, augmented hearing would allow the wearer to hear low-volume sounds, such as whispers that other people could not hear. Doing so would add a playful element, as it is an unusual feature that evokes exploration and curiosity.

## 7.2. The Tail

### 7.2.1. Explaining the Tail through the design space

The Tail is situated in the upper-right quadrant as the wearer encounters both an altered body schema and body image. The wearer encounters an altered body schema, especially when trying to sit down for the first time: they need to get used placing themselves on a seat in quite a different way to avoid squashing the Tail. Also, the movements of the Tail can affect the wearer's movements as it reacts to and amplifies the wearer's hip movements. These features add gamefulness to the extension as the wearer might seek to "master" the movement or otherwise incorporate it as part of their repertoire.

The Tail's designer explained that the wearers' body image is altered because they can amplify their self-expression by wearing a tail and through the altered movement possibilities. For example, as the Tail reacts to and amplifies the wearer's hip movements, a wearer reports how she feels her movements are more feminine to the designer. Other changes aside, the mere sight of a human with a tail is probably enough



to claim an altered body image. However, as the wearer does not see their own tail (in contrast to Monarch, for example), their body image is probably altered to a lesser extent, and extended use may even lead to them forgetting they are wearing it.

### 7.2.3. Extending the Tail through the design space

The design space helps us envision alternative versions. For example, if we move it to the right on the horizontal dimension, i.e., altering the body image even more, we are inspired to think about how we could “dress up” the Tail. The Cosplay community – which is targeted as a user group by the company that makes the commercial version of the Tail – has been encouraged to cover the Tail in highly visible material, such as fur (see the associated website (Cosgear, 2021)) that can fit to the rest of their costumes, which might even be dyed in highly visible colors, like pink. However, to facilitate lower levels of alteration of body image, we can envision using materials and colors (such as camouflage) that blend the Tail into the background rather than making it more visible. These uses would reduce the extent of altered body image while maintaining the extent to which the Tail alters the body schema.

If we move the Tail towards the bottom of the design space, we are encouraged to consider how to reduce the extent to which the body schema is altered. Examples of reduction involve shortening the Tail or including computational stability functionality, as gimbals offer. The Tail could also include sensors that detect obstacles and prevent it from touching/colliding with them when it wags. The designer of the Tail chose a modular design approach, whereby individual components could be easily swapped and replaced with other functionality, making these changes straightforward. By combining these changes with the camouflage approach mentioned above, we would end up with a “spy”-type experience, which sits in the lower-left quadrant, opposite to the upper-right quadrant in which the Cosplay version of the Tail is situated.

## 7.3. Arm-A-Dine

### 7.3.1. Explaining Arm-A-Dine through the design space

Arm-A-Dine alters the wearer’s body image because the robotic arm extends significantly from the body, and thereby alters common conceptions of how many arms we have and where they are positioned in relation to our body. These arms are further explored when the player feeds the other player, leaving one’s intimate zone and entering the eating partner’s intimate proxemic zone (Greenberg et al., 2011; Hall, 1969; Mueller et al., 2014). Moreover, the vest affects the extent to which the wearer can express themselves via their clothing.

Arm-A-Dine also alters the wearer’s body schema as it adds the functions of a third arm, or at least it adds feeding movements to the wearer’s body schema. This feature extends the wearer’s body schema, forcing them to reconfigure the internal organization of their limbs and movement repertoire.

Furthermore, the bodily extension adds weight through the mechanical construction of the robotic arm and through the vest the user is required to wear, which serves as a mounting surface for the robotic arm. As a result, while this bodily extension system extends the wearer’s ability to grab food and feed it, even if their arms are busy, it also hinders any fast or light movements because of its size and weight.

With the alterations of the body image, we, therefore, place Arm-A-Dine into the “mascot” quadrant of the design space because of how the aforementioned aspects of the system alter the wearer’s body schema and body image.

### 7.3.2. Extending Arm-A-Dine through the design space

We can envision alternative versions of Arm-A-Dine by exploring the body schema dimension. For example, we could employ electrical muscle stimulation (EMS) to facilitate similar autonomous feeding actions using the wearer’s own arm and controlling their muscles by applying a small electrical current. This change would reduce the physical size and weight of the system (Lopes and Baudisch, 2017),

allowing the wearer to explore the role of control in interactive feeding scenarios but with a less altered body schema and body image.

Alternatively, we can alter the body image by decorating or concealing the robotic arm with camouflage colors. The designer mentioned that they have considered putting fabric around the mechanical arm to direct the focus on the food. However, they ultimately decided against this change because they learned that participants appreciated being able to visually inspect how the robotic arm functions mechanically. Nevertheless, there are opportunities for altered identity play if the robotic arm resembles the wearer’s “third” arm by dressing it like the wearer’s other arms.

## 7.4. Monarch

### 7.4.1. Explaining Monarch through the design space

Monarch extends the wearer’s body schema through the kinetic textile that expands the shoulders (albeit not by much), limiting their ability for action by some (small) extent. The shoulder pads are located just within the wearer’s peripheral vision, allowing them to perceive when they expand or contract. Furthermore, wearers can quickly confirm if the system correctly interpreted their muscle tensioning by turning their head.

Monarch alters the wearer’s body image as the designers explained how they were comfortable wearing the system at parties because they believed that they were not as exposed to bystander judgments as they might be, for example, in a job interview. This phenomenon underscores this paper’s point investigating bodily extensions in play settings as it is more accepted to explore different norms than outside the magic circle of play (Montola et al., 2009). They said it attracted the welcoming attention of others. As such, we would place Monarch towards the right side of the design space (x-axis), and on the y-axis lower than Arm-A-Dine and the Tail, but higher than Wiggles. We would argue that, compared to the Tail, Monarch sits more to the right end of the dimension (more significant alteration) because the wearer can more easily see how the system responds to their input and, thus, is more aware of the system constantly.

### 7.4.2. Extending Monarch through the design space

We can envision moving Monarch to the upper-left quadrant by reducing how much the system alters the wearer’s body image. For example, we could move the shoulder pads further back and out of the wearer’s vision while keeping them visible to bystanders, for example, when worn on a full tram. While being unable to see the pads does not ensure an unaltered body image, it might facilitate a higher likelihood that the wearer forgets that they are wearing them, affecting their body image. However, the conversation partner will still perceive the interactive shoulder pads despite minimal alteration. Such a feature might make the extension more playful as the conversation partner will see the wearer with an extension, and the wearer will, thus, perceive an altered perception of self from the outside.

Designers could also move the system to the lower-left quadrant of the design space, thereby reducing the extent of alterations to the body schema by reducing the size of the shoulder pads. However, this change would also affect the (intended) likelihood that conversation partners will perceive the pads’ movements.

Designers could also move Monarch more to the lower-right quadrant, leaving the body schema primarily unaltered. Further exploration into kinetic textiles will probably help facilitate this change. For example, we can envision the use of shape-memory alloys (Muthukumarana et al., 2021) to create shoulder pads that move similarly to Monarch while affording lesser alteration of the body schema because they integrate more subtly with existing fashion than the original servo motors can.

### 7.5. Discussing the framework to relevant literature

We can now plot the examples we discussed in the related work section in the design space, highlighting its descriptive power (Fig. 12). We point out that this plotting is based on our assessment of the experiences reported in prior work; therefore, this is an ad-hoc estimation of where participants might place their experiences. Furthermore, we highlight that with the putting on/taking off that bodily extension experiences involve, their actual positions within the design space are probably better seen as trajectories (Benford et al., 2009a) rather than being fixed points. Nevertheless, their position might serve as illustration where their core experience might most likely be located.

We presented the design space, including its four bodily extensions from our designers and established prior work, with the hope that designers will find it useful through, for example, being able to anticipate what eventual user experience they can expect when designing their systems. We now discuss the relevance of the design space regarding some bodily extensions from more recent work, specifically the case study presented in the PneuMa project to further demonstrate the utility of our work, including its relevance to most recent developments (Saini et al., 2024). The authors of the work proposed three bodily extensions that promote movement in scenarios across everyday life that often result in playful experiences, as evident by an associated study. The three bodily extensions they discuss, namely, “Pardon?”, “Bye-Bye” and “Take-a-break” concern different user experiences across our design space. Firstly, the “Pardon?” bodily extension is worn behind the ear and activated by a vocal phrase from the user (sensed by an accompanying mobile phone app using speech detection) to “enlarge” the user’s ear through a pneumatic bladder that makes the ear appear more prominent in size while moving it forward to increase the chances of auditory waves being directed into the ear. This artifact could be placed towards the bottom-right of our design space (“model”). The bladder is placed behind the ear and, hence, invisible to the user. This means that there is probably minimal alteration to the body image (there is some alteration, as the user needs to wear a shoulder bag). However, the design goal was that when the bladder is inflated, the ear will get bigger, and in response, onlookers will be more likely to notice it, making it apparent for the

onlooker that the user is listening. Hence, the body image might be altered. Furthermore, the body schema might be changed as the wearer now has a bigger ear, which might affect how their hair falls. This example shows how a bodily extension can move across the design space as part of the interaction trajectory (Benford et al., 2009a), depending on how much of the wiggling is becomes visible and depending on the (emotional) state of the wearer. The playfulness that the system facilitated mostly arose through the moving of the ear, speaking to the Wigglears experience: moving ears are associated with laughter, where onlookers are surprised to see ears moving in response to any conversations they are having.

Second, the bodily extension “Bye-Bye” comes in the form of a pneumatic bladder worn by the user on their hand and activated by the vocal phrase “Bye-Bye” (again sensed by an accompanying mobile phone app using speech detection) to prompt a goodbye waving movement of the hand. The intention behind the design was to facilitate more embodied goodbyes by promoting good-bye gestures when people say good-bye to one another. This bodily extension could be placed somewhere in the upper-right part of the design space. This is because the system alters the user’s body schema when it prompts the goodbye movement, moving the user’s hand from closed to open, hence changing the user’s sense of where their fingers are in space and in relation to their hand. Furthermore, since the bladder is worn on the hand, which is visible to the onlooker once the hand is open, the system will likely affect how the user sees themselves (as being controlled by a machine, maybe?). The result can be an alteration of the user’s body image. Playfulness mainly emerged from people being surprised by the bodily movement, similar to “Pardon?”. In addition, users in the associated study used the freedom that they have over their hand and arm to complement the system-facilitated movement, for example, to amplify it further by supplementing it through an exaggerated arm movement, making the good-bye gesture a rather large one, which facilitated laughter.

Finally, “Take-a-break” promotes taking a break from work through embodied means, inspired by the “Pomodoro” technique that suggests taking a break every 25 min. The system includes a bladder worn on the palm while working with a conventional keyboard. The bodily extension

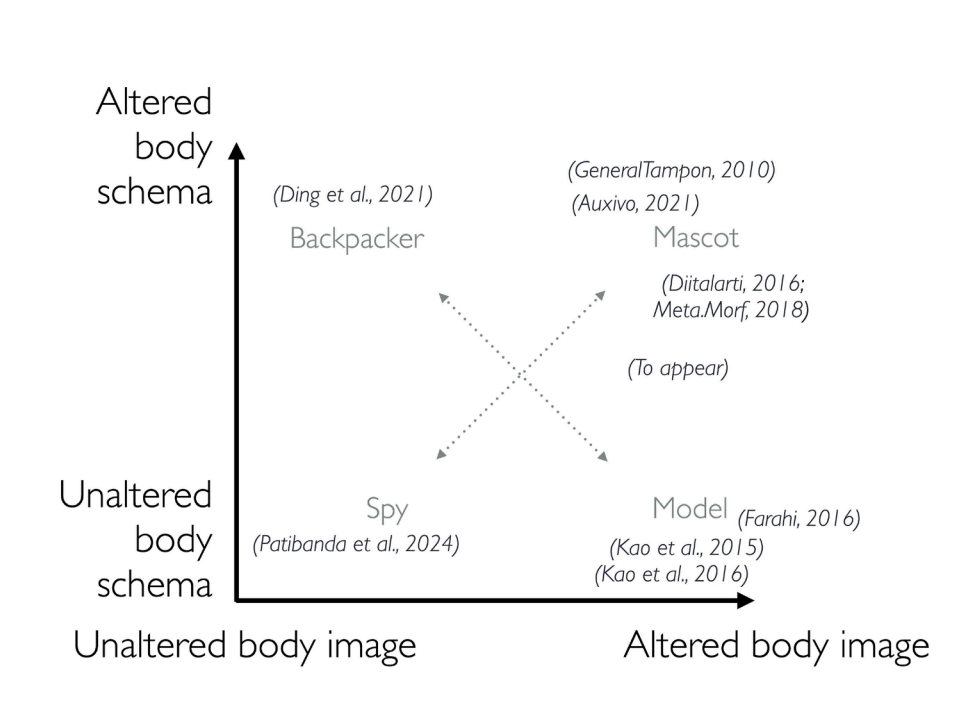


Fig. 12. Examples from prior work are plotted in the design space.

is activated when 25 min have passed (preset by the user): the bladder is inflated to push the user's hands away from the keyboard, helping them take a break through physically suggesting to move "away" from work. In our design space, this bodily extension could be placed near the upper-left quadrant as it alters the body schema by moving the hands away from the keyboard while having a minimal effect on the body image as the bodily extension is mainly hidden inside the user's palms and not very visible between the keyboard and the hands. Playfulness primarily emerged through the users being surprised that the time was already up to move away and the facilitated movement that almost "enforced" a break, whether suitable at that particular time or not.

We note that while these bodily extensions were designed to promote movement in everyday scenarios, they were deemed to be playful by the users in the associated study within the context of usage and, hence, can be situated within the design space presented in this work for validation through prior literature (Ledo et al., 2018), we believe.

## 8. Design strategies for bodily extensions based on body schema and body image

We present a set of strategies for designers interested in developing playful bodily extensions based on body schema and body image. These strategies are intended to assist designers navigating the design space and applying the dimensions to their creative process. We target junior designers and non-professionals with these strategies as we believe they can benefit from such initial guidance that could be complemented with more comprehensive general design advice later.

Our strategies were identified through an iterative process in which we reflected on what we had learned from our conversations with the designers and our own practice. We checked each strategy amongst all authors to ensure that they arrived through a process of consensus. However, we did not check these strategies with the designers, instead, we leave this for future work. Nevertheless, we believe that these strategies can be useful for others as they have been derived from practical experience and reflection across a wide range of design expertise. Furthermore, the strategies are grounded in design practice and hence might offer value that is readily applicable to designers starting out in the field. As little prior guidance is available, we hope that these strategies can serve as valuable starting points. Still, these strategies might need updating once more knowledge becomes available in the future.

Our selection criteria for the design strategies were that they could be readily considered by designers starting out with designing playful bodily extensions, that is, do not require prior expertise in designing such systems. Furthermore, we aimed to select strategies that, albeit maybe obvious to more experienced designers, might serve as a careful reminder to aspiring junior designers. We also selected these strategies because we believed that they could be easily understood without much theoretical knowledge about body image and body schema beyond what is discussed in this article so that designers do not need to engage further in the literature before they can start designing. We also selected those strategies we believed were easily comprehensible in textual form, acknowledging that design often relies on tacit knowledge that can be difficult to convey in an article. Lastly, we selected those strategies we believe would be valued by designers as they would support a wide range of systems without requiring too specific hardware or software skills.

We do not see our set of strategies as a final list, nor do we claim that these strategies guarantee results. Rather, these strategies might be useful as a starting point or when a designer is unsure about what design decisions to make during the process of creating systems. Given that we have developed this article using the concepts of body schema and body image, the broader fields that are concerned with these concepts might contribute further to current and future strategies, while they might also learn from our work. We hope that these strategies are both abstract enough to be applied to a range of systems and sufficiently precise and relevant to design practice to be immediately useful in the field.

We recommend that designers interested in developing bodily extensions first read through the entire list of design strategies. They should then identify which ones apply to their particular application context or scenario. These strategies need not be followed in any pre-established order, nor must any or all of them be implemented. Rather, they should serve designers as an initial list for consideration. We begin with a summary of the design strategies (Table 2).

### 8.1. Performative limb: consider designing the bodily extension as a novel socially performative limb for playfulness

"Social interaction" was one of the most prevalent interview themes, and we note that prior work on wearables also highlighted this key theme for playfulness (Buruk et al., 2019; Dagan et al., 2019). Adding to this work, our interviews with the designers revealed that bodily extensions can become novel socially performative limbs that interact with others or even with the self, resulting in playful experiences. Unlike prior work on wearables for social interaction, performative qualities are here concerned with the body schema since the bodily extensions can free up, replace or extend existing bodily social interaction mechanisms such as gestures and body image-related reactions of the self, such as (no) eye contact or blushing. Performative limbs can even augment human social interaction capabilities by giving an extra mode of expression for playfulness and creating a new bodily language among wearers and any bystanders. Of course, these aspects of the bodily experience could produce unexpected social effects, such as excluding others without extensions. All bodily extensions by our designers can be seen as novel socially performative limbs. We now describe how designers can consider bodily extensions as a novel socially performative limb for playfulness through exaggeration of bodily communication, autonomous reactions to others, and exclusive communication language. We point out that these are options that designers can consider as they have the potential to facilitate playfulness. However, there could be others, so designers should not be restricted to only consider these but rather see them as starting points for further exploration.

#### 8.1.1. Exaggeration of bodily communication

This design strategy can be used to exaggerate the wearer's subtle emotions to facilitate playfulness. The designer of Wigglears explained that others sometimes interpreted the ear's wiggling as a sign that the wearer's emotions changed: "*Cause they'll be like 'Oh, you just lost all your money [in a Monopoly game], and your ears are wiggling!' And I guess it kind of drew out the fact that I was feeling something, drew all the attention towards what I was feeling and then kind of made it playful because my ears were wiggling and that's funny.*" Although the moving of ears is quite

**Table 2**  
Design strategies.

Strategy title	Strategy
Performative limb	Consider designing the bodily extension as a novel socially performative limb for playfulness
Control	Consider supporting varying levels of user control over the bodily extension
On/off-boarding phases	Consider different phases of the incorporation process as a resource for playfulness
Types	Consider accommodating different levels of playfulness in different contexts
Identity	Consider altering the body image and the body schema of the wearer for transformative identity experiences
First-person	Consider first-person perspectives for nuanced bodily expressions, intuitiveness in expressions, and longer-term engagements around body schema and body image
Iterations	Consider iterations for expressive playfulness and bodily aspects of playfulness when designing for body schema and body image
Bodily Playfulness	Consider stimulating bodily exploration and bodily perception and design for bodily achievements and mastery in relation to body schema and body image

subtle to the wearer (and even noticeable at times), the unfamiliar movement (and the sound produced by the ears) affects onlookers' reactions, also recalling that we perceive many social cues from subtle movements (Weiss, 2013). In these ways, this strategy is expected to place the design in the upper- or lower-right quadrants of the design space.

#### 8.1.2. Autonomous reaction to others

Arm-A-Dine demonstrates that bodily extensions can be part of the body that react to external social cues (here: sensing a partner's "sad" or "happy" facial expression) without needing any additional prompts from the wearer's body. In this way, the system is a sensory addition to the body that scans the external environment around the body and provides reactions depending on the social situation, which can be playful. The unpredictability of the reactions (when the robotic arm hesitates in the middle, "teasing" the participants) adds ambiguity (Gaver et al., 2003) to the experience, which appears to induce playfulness. The designer of Arm-a-Dine explained how this ambiguity caused by the emotional response of others was discovered accidentally during the design process: "So, it started according to the expressions of the other person. And for 10 minute, we all, like, everyone was thinking what exactly is really happening? Who is controlling the robotic arm? And that ambiguity created so much laughter, laughs [...] And then we made the next prototype where my expressions control your, your arm; your expressions control my arm. And through that way, it became playful, it became an engaging social experience." In other words, the design altered the wearer's action space, and in doing so, it also altered the wearer's social cues and normative understanding of interpersonal communication.

#### 8.1.3. Exclusive communication language

It is interesting that Monarch when worn together with others, created a mutual language among wearers, communicated through the bodily extensions. The designer explained their experiences of attending a social event at which multiple people wore the extensions: "I felt like the people who weren't wearing them felt weird because we had this extra mode of expression that they couldn't access, you know, so, like, they couldn't respond because they didn't have this prosthetic or this extension. So, it became this kind of like, not a secret, but more like an open channel of communication between those of us who were wearers that this other subgroup didn't have access to. So, it created this weird hierarchy of nonverbal communication." In this way, Monarch created a shared bodily understanding among wearers and allowed them to communicate in a way that others could not. This anecdote indicates that having extensions in a group setting that exclude people who do not have access to these devices could be problematic. In other words, the design features created a new cultural language that challenged normative behavior that for outsiders was difficult to understand.

### 8.2. Control: consider supporting varying levels of user control over the bodily extension

Our interviews highlighted that the wearer's level of control over the system is a critical element in incorporating bodily extensions into the body. Prima facie, we might presume that this incorporation should be a straightforward process. While this ease of incorporation and interaction can be the case in some instances, especially when giving users a chance to operate their extensions in the way they want, taking away a level of control can also lead to playful moments. Thus, during the design process, it could be beneficial to explore the different experiences that different levels of control could facilitate.

#### 8.2.1. Unintentional surprising interactions

With Wigglears, unexpected movements of the ears were frequently observed. According to the designer, those unexpected movements attracted bystander's attention to the ears and prompted reactions. When we were ideating with the designer on other possible uses of

Wigglears, the first idea that came to mind was a "try not to wiggle" challenge, where the wearer tries to control their emotions to keep their ears stable. This idea, readily available to wearers of the current system, demonstrates how varying levels of user control could lead to playful experiences.

Arm-A-Dine used the lack of control over the bodily extensions to prompt playful experiences. It is the only project that explicitly takes control from the wearer and offers it to another person. Wearers had to coordinate their own body movements to respond to this take-over of the arm, negotiating it with the partner's position when feeding. In this way, the wearer's body schema was externally altered, with the wearer trying to respond to it at that moment and negotiate the balance of control between the wearer, system and partner. According to the designer, this shared control with the robotic arm and another person was part of the enjoyment of using Arm-A-Dine. Shared control also created a space in which the wearer was more mindful of the expectations and desires of the other person with whom they were eating. The designer of Arm-A-Dine described this as follows: "It facilitated social interactions and broke down the ice. It helped them to, you know, understand or know a lot more about the person. So, I would say that this also works as an agency for educating how the other person is feeling about you and how you're feeling."

This strategy aims to surprise users by manipulating their body schema. This manipulation might move the extension into both the upper and lower parts of the design space since even a tiny, unexpected manipulation of the body schema might create playful moments, as Wigglears showed. The more significant manipulations, such as one relating to Arm-a-Dine, that locate the extension in the upper part of the design space might work better in playful situations where the whole body is included.

#### 8.2.2. Moments of accidental activation

The designers deemed the times when the Monarch system was accidentally activated playful. This unintentional activation can prompt reactions from other wearers, especially in a group setting. For example, on one occasion, the wearers began flapping their own wings after another wearer's wings were unexpectedly activated. Nevertheless, carefully adjusting the control level over bodily extensions can be critical because a lack of control can sometimes lead to unpleasant experiences. For example, the designers of Monarch noticed that taking control away from wearers was sometimes alarming: "We designed a particular control panel, which meant that there was an easy-access off switch, you know if the things had gone crazy. 'Cause we found that people would get really uncomfortable when it started doing things that they didn't want it to do. So, there was also, you know, like a sensitivity knob, so that they could kind of tweak it."

These comments highlight that if the bodily extension appears out of control, wearers' body schema and body image can be disrupted, making wearers uncomfortable. Designers need to consider this risk. Accidental activations that will alter the body schema dramatically might induce anxiety and, at worst, be dangerous for the user. Accidental activations might work better when those accidents create amusing social situations, which suggests that it might be safer to design playful extensions that occupy the lower-right part of the design space (i.e., low alteration of body schema and high alteration of body image).

#### 8.2.3. Complete control for intuitive communication

The Tail project aimed to give the wearer complete control over the bodily extension as highlighted in the designer's description of the iterations in the design process. In the first version, the Tail was controlled by remote control, which the wearer considered insufficient control. Therefore, a control mechanism was implemented in the next iteration that allowed the wearer to control the Tail with hip movements. The designer defined playfulness as experiencing the Tail and adjusting to it. In this way, one of the design aims was to make the wearer feel that the Tail is a part of the body and that they have full control over it. Thus, control over the Tail was an essential element of acquiring a new body



part; the designer described this as intrinsically playful.

Allowing for more control can also afford playful communication. The designers of Monarch hoped that, after learning how to use its different modes, Monarch wearers could adopt more sophisticated communication methods, for example, by controlling the frequency of wing-flapping. This control could make novice users more comfortable using such a novel system while retaining the playful aspects due to the unfamiliarity and ambiguity of this novel communication. One of the Monarch designers described the different modes of expression that can be performed with this level of control: *"Sometimes, it could be quite subtle, similar to like raising an eyebrow or shrugging the shoulders. Kind of, like, light fluttering, like a quiet hello. When we talked with people, some people talked about opportunities for it to be aggressive, but a lot of people talked about opportunities for reaching out or flirting."* This description suggests a higher level of control could be a way of altering how people are perceived, possibly affecting their body image and the way they socially and culturally interact with the world.

### 8.3. On/off-boarding phases: consider different phases of the incorporation process as a resource for playfulness

Incorporating bodily extensions into the body schema is a process that begins with putting the bodily extension on, or what we call "on-boarding". "On-boarding" is followed by learning how to incorporate the bodily extension into the body schema (especially if there is a large extent of alteration). This leads to the phase where the bodily extension is fully incorporated into the wearer's body schema. The final phase involves taking the body extension off, or off-boarding, which can disrupt the body schema since the wearer might experience a loss of a body part. We highlight that these different phases should be designed carefully. They speak to the various phases of playing a digital game: the engagement phase (the beginning of interacting with a game), the engrossment phase (the phase where the mastery over controls is established), and the total immersion phase (being inside the game by experiencing absorption, presence, and flow) (Brown and Cairns, 2004). Complementing these digital game phases, we find that the phases associated with bodily extensions need to also consider the final phase because this phase can involve a bodily sensation of missing an augmented state of the body when the extension is removed. The different phases were highlighted in other ways in the interviews, which we explain further below.

#### 8.3.1. Explorative joy of onboarding

Wearing the extension for the first time during the onboarding phase can induce excitement and pleasure. The designer of the Tail highlighted one phase of the playful experiences caused by the system when walking with it and trying to understand how the body can control it: *"It is an interesting experience, just the experience of walking with a Tail and to learn to master how to move it, that in itself is play."* Similarly, the first moment when wearers started using Arm-a-Dine was associated with playfulness facilitated by the exploration of using the robotic arm: *"I think all of them [wearers] were really explorative, very expressive. They were very curious to try out different ways to figure out ways on how to trick the system, and it created a lot of joy, laughter, anger sometimes when they didn't get the food that they wanted to."*

Sometimes, this first phase of acquisition of the bodily extension resulted in negative feelings, such as frustration. Consequently, the designer adjusted the difficulty associated with learning how to use the system. He said that if learning how to use the system was too hard, it could repel users and prevent efforts to engage with it, while if it were too easy, it could result in boredom. These remarks align with the theory of flow, which suggests that an optimal experience balances anxiety and boredom (Csikszentmihalyi, 1990).

These issues are helpful in understanding the upper part of the design space. The joy comes from users' exploration of their altered body schema and understanding the different ways their extensions

manipulate it. Consequently, this strategy might be most effective for the bodily extensions of the mascot or backpacker quadrants.

#### 8.3.2. Adjustment with additional feedback

Although all designers agreed that their bodily extensions might become incorporated into the body schema, the fact that they are not part of the organic body means that additional prompts might be needed to facilitate this incorporation. For example, the Tail designer stated that he would want to add haptic notifiers to inform the user about the current position of the Tail and facilitate integration into the body schema.

The designer of Wigglears asserted that such additional modalities could be used to playfully conceal the undesired outcomes of the underlying technology. For example, being positioned close to the ears, the Wigglears servo motors produced a sound not part of the intended experience. The designer mentioned that the sound was sometimes why she realized that her ears were moving. We brainstormed how to improve the design of Wigglears, and the idea of playing a pre-selected sound, perhaps one that is funny and enjoyable, came as a possible solution to this issue. In this context, secondary input and output modalities can negatively or positively affect the experience of integrating a bodily extension, and we might draw on playfulness as a way to diminish or amplify those modalities.

#### 8.3.3. Offboarding behavior

The designers of Monarch and the Tail talked about the bodily experiences that can occur after removing the bodily extension. The Tail designers mentioned feeling "tail-less" upon removing the Tail from the body after an extended time in use. The Monarch designer mentioned that the extra mode of expression granted by this extension could be something to which people become accustomed: *"One thing that I found interesting in the process was the moment when people were taking them off. Even though wearing was relatively short, just because of that physical expressiveness, they became attached to the object quite quickly. So, there is a sense of loss in terms of, like, we had people being 'I don't want to take it off.'"* As with on-boarding, off-boarding also induces a notable bodily experience, though it involves the sense of losing a body part or augmented ability. The wearer's experiences of loss during such moments could be mitigated using pre-programmed behavior, such as a curling up of the ears (Wigglears) or a "good-bye flapping" of the wings (Monarch) (an idea coined by the authors of this paper).

This strategy could be helpful in designing bodily extensions that alter the body schema significantly, and it relates most to designs that are placed on the very upper part of the design space. The offboarding experience is essential for bodily extensions that alter the body schema to the extent that wearers would feel their absence as a bodily experience after the extension is removed. Such feelings of loss might be mitigated using playful system behaviors that keep wearers excited during the removal process.

### 8.4. Types: consider accommodating different levels of playfulness in different contexts

Our designer interviews suggested that the bodily extensions might afford different levels of playfulness in other contexts. For example, while intrinsically playful contexts such as game settings or parties may quickly render the movements of the bodily extensions enjoyable and attractive, more serious contexts such as a lecture theatre or an office, may not accommodate the same level of playfulness. All designers discussed the playful affordances that change according to context and provided detailed accounts of how the context informed how the body image was altered.

#### 8.4.1. Adjustments to lived experiences and contexts

The Wigglears designer mentioned that using the system in a game context, which is already open to playful interactions, increased the

possibility for others to react to the wiggling movement of the ears. Furthermore, the ambiguity regarding the reason behind the ears wiggling prompted co-players to believe that the wiggling was a response to game outcomes. In this environment, these ambiguities led to laughter. In contrast, when the designer wore the system while listening to an online lecture, she was distracted when the ears started to move. After noticing that the ears were moving, the designer focused on this movement and its reason instead of following the lecture. Here, the appropriateness of the extensions was not a matter of social acceptability. Instead, the personal experience the extension induced did not fit the context. In this sense, instead of thinking that extensions only belong to specific situations, designers can interrogate how the design can be extended to accommodate these different situations. For example, while the emotions the extension detects and the movements it generates can be designed to prompt laughter in one setting, in a different setting, like a lecture, it might detect low levels of wearer concentration and help them re-focus on the lecture content. While the alteration to the wearer's action space is less dominating, the design's behavior takes on a dominating role. The consequence is that the design becomes part of how the wearer perceives themselves as a social being among others, here explicitly induced by the context.

Here, both social acceptance (body image), and intrinsic bodily feelings (body schema) might be disrupted if the wearer's lived experiences and their context do not match. While adjusting our body image according to the context is a common practice (e.g., choosing clothes depending on the event that will be attended), it might be less familiar to account for the bodily experiences induced by bodily extensions even though they can be inappropriate in specific contexts. Consequently, we recommend designers of bodily extensions that would fit in the upper part of the design space consider the appropriateness of the lived experiences they produce to the contexts in which they are used.

#### 8.4.2. Multiple wearer situations

Monarch has been worn by its designers in many different playful and serious contexts. However, according to the interviews, even if the context is the same, the number of people who wear bodily extensions can also change the level of playfulness. For example, one of the designers of Monarch tried it in two ways in a work environment: first, with only her wearing the extension, and second, when she and multiple others wore Monarchs. The designer explained that wearing it by herself felt like using a loud keyboard that disturbed others. In contrast, numerous people wearing Monarchs triggered a break from work that everyone around the wearers joined and enjoyed.

This strategy relates to bodily extensions that exist on the right side of the design space. While an extension might be considered socially unacceptable if worn by only one single person, multiple people wearing extensions might increase its acceptability. Consequently, designers should consider designing interactions that might facilitate multi-user interaction if their bodily extension design remains on the right side of the design space. However, doing so should also consider how bystanders would perceive such an event. They might feel intimidated socially and culturally. Designers should be aware of such complications.

#### 8.4.3. Sudden transitions between contexts

Another experience conveyed by the designers of Monarch was how intrinsically playful environments can exist adjacent to more neutral environments. For example, in a conference that hosts an interactive exhibition, wearers of extensions may need to walk across other conference areas that do not necessarily afford playfulness. The Monarch designer referred to *"just this feeling of like crossing the boundary from this space where it's kind of expected to, just mingling with all these other things. And it was just feeling super weird, but suddenly the playfulness faded away, and it was just strange. I think that the kind of invisible boundaries [of] play spaces are really interesting."* The unfamiliarity and strangeness of bodily extensions make them suitable for contexts in which this kind of

unconventional body image is acceptable because these places can be considered magic circles of play (Salen and Zimmerman, 2003), within which the community accepts the wearing of, and the moving, performing and playing with such systems. However, this experience also indicated that we might also need to consider designing bodily extensions that accommodate sudden changes in the wearer's context.

As with multiple-wearer situations, this strategy would be more applicable to the extensions located on the right side of the design space. However, when applying this strategy, designers might consider designs that can dynamically transition between the left and right sides of the design space. These transitions might be facilitated by changes to color, texture or form factor or by changes in the extension's behavior (for example, a tail that curls up to conceal itself inside a jacket when the wearer changes contexts).

#### 8.5. Identity: consider altering the body image and the body schema of the wearer for transformative identity experiences

Identity is a significant force of wearables research because wearables can be closely connected to self-expression, fashion, and personal styles and thereby directly alter the body image (Genç et al., 2018; Tomico et al., 2017). However, the body schema also plays an essential role in defining identity. An intriguing example of this role is the brass anklets worn by Nigerian women between 1930 and 1940. Due to their weight, these anklets affected the posture of the women wearing them, and this posture came to represent their wealth (Adams, 2007). We believe that a postural change can have a considerable effect on the perception of the body and, therefore, the body's performative capabilities. The possible effects of bodily extensions on the wearer's identity transformation were also discussed during the interviews. Such transformation refers directly to how wearables could alter the wearer's and bystanders' perception of body image.

##### 8.5.1. Transformation through accommodated behavior

The Tail provides an example of how extensions can significantly alter both body image and schema because they affect many aspects of the body. First, the Tail is a flamboyant addition that alters the body image. However, controlling the Tail also demands unfamiliar movements. A wearer must perform uncommon postures and move their hips to activate the Tail, which stresses the wearer's identity. The Tail's designer explained: *"[a distinguished researcher] has a very good description in her book about her experience of trying it [the Tail] out and how it, sort of, changed her feeling of being female."* In response to this type of experience, we propose that one way to highlight the experiential effects of extensions is to design them in a way that would lead to identity transformations through bodily movements and posture.

This strategy is concerned with altering the body image through modifications of the body schema and, thereby, can be applied successfully to the designs in the upper part of the design space. While it is known that the shape and the look of wearables are closely related to self-expression and identity (Buruk et al., 2019; Genç et al., 2018) and, thereby, body image, this strategy suggests that a similar impact on body image can be induced by how the wearer changes their behavior when wearing bodily extensions. Consequently, designers should explore how the system can change the wearer's behavior and consequently speak to and transform the wearer's identity.

##### 8.5.2. Attitudes induced by behavior of bodily extensions

Although Monarch did not facilitate significant posture changes or body movements, the system was still deemed to be altering the wearer's identity by changing how they communicate with the outside world. For example, one of the Monarch designers said that the shoulder pads made her behave more extrovertedly: *"I think even if you aren't extroverted, it almost, like, makes you that way. Cause I do not, [other designer] or I, would identify ourselves as an extrovert, but I think when, when we've talked about our experience wearing these, it, it either like helped mitigate, uhm, you know,*

like at the dance party [...]". The designers also mentioned that they chose to continue to develop the Monarch among other projects because the interaction provided by the shoulder pads seemed more extroverted and more playful. This intentional choice of extroverted interaction through shoulder pads also affected the designers' first-person experiences and how they regarded their identity in social situations.

#### 8.6. First-Person: consider first-person perspectives for nuanced bodily expressions, intuitiveness in expressions, and longer-term engagements around body schema and body image

We now describe how designers can consider first-person perspectives to understand nuanced bodily expressions better, intuitiveness in expressions, and longer-term engagements around body schema and body image for playfulness by applying their own lived experiences with their designs.

##### 8.6.1. Nuanced bodily experiences for playfulness

All designers emphasized the importance of their personal first-person engagements with the bodily extensions during the design process to identify potential nuanced bodily experiences for playfulness. One of the Monarch designers explained that she always tells her students: *"Wear your wearable before making anyone wear it"*. The designer of Wigglears also emphasized the importance of experimenting while wearing bodily extensions: *"I guess the most interesting thing while designing it, was kind of being able to picture what I wanted in front of me and then feel how that reflects while I'm wearing it. Since I was the one who was actually using what I designed, I could wear it and then make, like fine-tune adjustments based on how it felt while I was wearing it."* This iterative process of understanding the nuanced experiences for playfulness appeared to be integral to the designers' development of the playfulness of their prototypes.

##### 8.6.2. Intuitiveness in expressions

Another important aspect that appears to benefit from the designer's personal first-person perspective is the intuitiveness of any playful expressions. As previously mentioned, bodily extensions can be considered social organs and used to create new types of (self-) expressions. In the first part of the design process, these expressions can be quite nuanced. Understanding whether they can be communicated intuitively requires the occurrence of many social interactions via which designers might want to qualitatively assess the effects of their communications. For example, Monarch's designers decided to iterate their design after realizing that it could facilitate more natural expressions: *"So these photos were from our, like, self-testing, to kind of see how this expression works as people socialize a little bit more naturally, uhm, which I think was kind of why we went with Monarch. It was a bit more extroverted in its expression. And, so, there was a little bit more relation between people and that kind of made it playful."*

##### 8.6.3. Longer-term engagements

Designers emphasized that they would like to be able to create longer-term engagements to support playfulness. As much as considering the opinions and experiences of a diverse group of users is vital for making sense of a design for different people, it is equally critical to obtain the personal perspectives of designers while iterating the design for playfulness. These personal first-person practices can help designers refine the nuanced bodily experiences (and their effect on body schema) that bodily extensions can introduce and understand their social effects (related to body image) as well as allow for longer-term engagements to assess the extensions in varied contexts. Prior work has already indicated the usefulness of the designer's personal first-person perspectives in HCI (Höök et al., 2018) and our work extends this to the design of playful bodily extensions.

#### 8.7. Iterations: consider iterations for expressive playfulness and bodily aspects of playfulness when designing for body schema and body image

Iterations are a natural part of every design process. Here we point to the potential of employing iterations for expressive playfulness and bodily aspects of playfulness when designing for body schema and body image. According to the designers, the emotive elements of the bodily extensions were mostly discovered during earlier iterations, while the experiences related to bodily aspects were found during later iterations.

Expressive aspects were usually discovered at the beginning of designing the bodily extensions. Even if the initial interactions with the bodily extension were "rough" and uncomfortable to wear, the designers could understand the possible effects by quickly iteratively testing them, just as the Wigglears designer did. Similarly, the Arm-A-Dine designers were testing their prototypes when one of the mobile phones recording the wearer's facial expressions dropped and started recording the facial expressions of a passer-by. This event produced a fun and playful moment during which there was ambiguity regarding who controlled the arm. This event led to the design decision that the expressions of the other diner would control the arm in the final version of the prototype.

On the other hand, the comfort and the novel bodily feelings induced by bodily extensions are also critical to the overall experience of incorporating extensions. The Monarch designers explained that in the V2 of the Monarch, they did not necessarily focus on the interactive parts fundamental to expressiveness and bodily experience. Instead, they primarily applied more minor "tweaks" to the extensions to make them more comfortable to wear and use, allowing more opportunities for playful experiences to emerge. Similarly, the designer of the Tail said that, concerning commercializing the Tail, user workshops had been organized to better understand user preferences relating to control and fit.

#### 8.8. Bodily playfulness: consider stimulating bodily exploration and bodily perception and design for bodily achievements and mastery in relation to body schema and body image

Following our interest on bodily play, several of the designers expressed experiences in this regard. While these instances are hinted at throughout the other strategies, we highlight the most significant situations in its own strategy. We base this strategy on Matjeka and Mueller's theory of bodily play (Matjeka and Mueller, 2020), emphasizing bodily exploration, perceptual stimulation and mastery as core elements.

##### 8.8.1. Stimulate bodily exploration

Designers could consider stimulating bodily exploration by adding features for varied and challenging movements, i.e., extending or restraining the wearer's actions space (Matjeka et al., 2021) to the bodily extension to facilitate playfulness. For instance, the designer of the Tail explained how wearing his tail fostered bodily awareness and exploration when he moved around, as it responded to his movement behavior – these situations appeared to facilitate playfulness for the designer. Also, the application of Arm-A-Dine encouraged bodily exploration by adding an extra arm to the wearer's body schema and, thereby, extending the wearer's action space. In this regard, the designers told of situations where the arm moved in ways that were opposite to what was anticipated, which led to joy and bodily exploration. In these instances, how the extensions moved together with the wearer challenged the wearer's notion of their available action space, i.e., body schema, making them explore their bodily composition and capabilities.

##### 8.8.2. Stimulate bodily perception

Likewise, designers can add features stimulating bodily perception and awareness to play with the wearer's body image. For instance, the Monarch and Wigglears stimulated the wearer's tactile senses by moving



slightly and these caused the wearer and any bystanders to perceive a change in the expected bodily expression and communication form, i.e., the wearer's body image. While the movements did not directly affect their movement capabilities, they stimulated their bodily perception and, thus, their bodily expression (and possibly any bystander's perception of their body language), drawing attention to their body image. The designer of the Wigglears reported how they could feel the augmented ears; this experience made them aware of how they looked to others.

### 8.8.3. Design for bodily achievements and mastery

To design for bodily play, designers can consider how the wearer can gain a sense of mastery by wearing the extension or obtain bodily qualities by adding achievement features. For instance, Arm-A-Dine encouraged the wearer to master it, as it would move strangely if the wearer did not manage it as intended. In other words, the designer had to learn its mechanics to master it.

Another speculative example could be if the Tail could enhance the wearer's sense of balance, like a balancing stick: the wearer could achieve bodily qualities that they would not otherwise have. These bodily qualities would also lead to a quest for bodily mastery and improvement. Designing for bodily achievements and mastery can add to the wearer's body schema as it improves the wearer's bodily skills and draws attention to their bodily actions with the consequences of experiencing superpowers and an altered action space.

## 9. Limitations and future work

We acknowledge certain limitations, pointing out that all research work that aims to derive implications for future designs based on insights from designers could have such limitations. For example, our design space and associated strategies have not yet been validated besides through our own practice. Nevertheless, we believe that our work can be valuable, as it can serve as a starting point for designers interested in creating playful bodily extensions. There is not much other guidance available, hence, our work might be appreciated as initial advice on where to start. Furthermore, we point to prior work that started with presenting theory in the form of design spaces and/or strategies that were validated only through existing designs (e.g. (Andres et al., 2022; Benford et al., 2009b; Byrne et al., 2020; Deng et al., 2023; Khot et al., 2020; Li et al., 2023; Mueller et al., 2017; Mueller, Kari, et al., 2018, 2020, 2021; Semertzidis et al., 2023)). Yet, it appears that such an approach could offer value to the HCI design community that is appreciated by others being able to learn about it (Velt et al., 2017).

We also acknowledge that we, so far, have only explored one way of naming the four quadrants. These names came from our own reflections on the data and our own craft knowledge of having designed bodily extensions. We believe that these names help in making the framework graspable for designers and offer easy-to-remember handles to engage with it. However, these names might also taint a person's engagement with it, subconsciously shaping what types of bodily extensions they might come up with. As such, we frame this as limitation of our approach and encourage future work to investigate what role, both positive and negative, such a naming can have on the design of future bodily extensions.

Taken together, we believe that our work has value, yet we acknowledge that future work could add additional insights by interrogating our design space and strategies. Conducting workshops with designers in which they use the design space and comparing these with workshops in which the design space is not used could be a helpful starting point. Furthermore, designs that used the strategies versus other work that did not use them could be compared to add evidence to their value. Different ways of adding validity to our work are examining additional playful bodily extensions and tracking future work that uses the design space and the strategies in their publications (such as suggested by prior work (Velt et al., 2017)).

We acknowledge that our current design space and strategies are only a starting point, that they should be developed further in future work, and that there are several pathways to do so. For example, we have currently only differentiated between high and low extents of each dimension. Further work could segment the dimensions into more fine-grained categorizations. This refinement could also help identify additional user experience types. Furthermore, additional dimensions could be added or examined separately, thereby acknowledging how complex and multifaceted integrating the human body and technology is. Design practitioners could also develop and explore additional strategies to assist the design for specific locations in the design space.

We also acknowledge that we have yet to understand the long-term implications of playful bodily extensions fully. For example, artist Neil Harbisson, who cannot see colors, has been wearing a bodily extension with a camera that allows him to "hear" colors. Scans of his brain suggest that over the years of using the system, his brain has become able to "see" the colors, rather than transform sound information into color representations. In this regard, his brain exhibits "significant changes in functional neural patterns, structural connectivity and cortical topography" (Alfaro et al., 2015). Understanding such long-term implications will help us shine a light on what it takes for users to adopt such playful bodily extensions, and we see such investigations as exciting areas for future work.

We also acknowledge that our considerations of the complex concepts of body schema and body image are in their infancy. Our work has only scratched the surface of body schema and body image regarding playful bodily extensions. We fully anticipate that advancements in understanding bodily schema and body image, most likely coming from other disciplines, will prompt and inform further work in playful bodily extension design.

## 10. Conclusion

In this article, we examined four different bodily extensions and conducted interview sessions with their designers to understand how to design playful bodily extensions. Design-oriented bodily extension projects that focus on experiential and playful qualities of extending the body are scarce, and our work can be considered the first step towards creating holistic design knowledge regarding the design of such artifacts.

Our design space around playful bodily extensions has helped us analyze existing designs. By looking at the design space, we have determined where existing systems sit and where we could "move" them in the design space to facilitate different user experiences. The design space dimensions have also informed our discussion of the designs, and they provided a way to articulate design differences. We hope other designers and researchers will benefit from this work.

Our work was motivated by the potential of playful bodily extensions. An integration approach can facilitate novel user experiences and playful bodily extensions can offer exciting new opportunities for users to experience their body, and hence themselves, in interesting and new ways. Understanding how to design such an integration between the human body and a computational system is an underexplored area, mainly because there is limited knowledge about the associated user experiences. In response, we have conceptualized playful bodily extensions as the foundation for an initial, accessible, structured understanding of the myriad ways human bodies and computational systems can integrate. Nevertheless, supporting integration is not always the right and only thing to do. In particular, we highlight that bodily integration can create ethical challenges (Grudin et al., 2018; Mueller et al., 2020).

Overall, we hope that our results can help researchers and designers of bodily play in their design and research endeavors to further this area of study, so that, ultimately, with our work, we bring more playful experiences to people's lives.



## CRediT authorship contribution statement

**Florian ‘Floyd’ Mueller:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Oğuz ‘Oz’ Buruk:** Writing – review & editing, Writing – original draft, Visualization, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Louise Petersen Matjeka:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Aryan Saini:** Writing – review & editing, Resources, Project administration.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Data availability

The data that has been used is confidential.

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